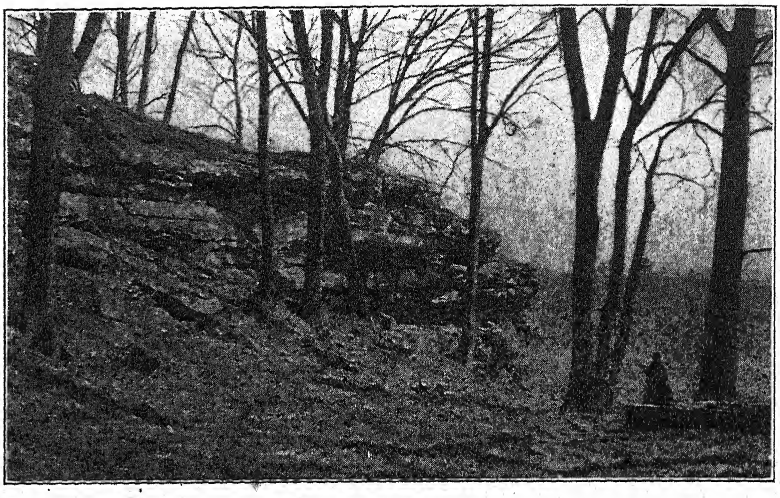

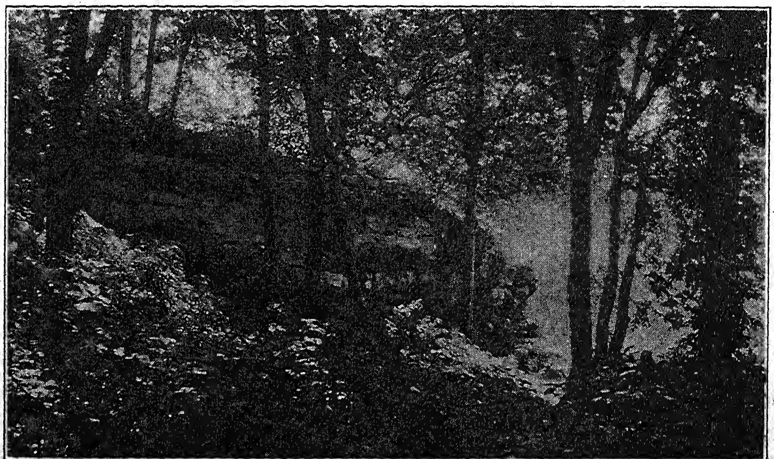

Growth:—the formation of thousands of new cells by successive divisions of old cells; the enlargement of these cells by means of water, foods, nutrients, absorbed from the soil or manufactured in the plant and transported here and there through stems, roots and leaves; the assumption by these cells of particular shapes and sizes, some becoming green, some colorless, some rigid, some tender and pliable, forming new leaves, twigs, roots, flowers and fruits. All these wonderfully complex activities are involved in the change of a March landscape into a June landscape.

Botany

A Textbook for College and University Students

By

WILLIAM J. ROBBINS

Professor of Botany, University of Missouri

and

HAROLD W. RICKETT

Associate Professor of Botany, University of Missouri

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PREFACE

THE material included in the following pages may differ in some respects from the reader's conception of what a beginning course in college Botany should be. It might be advisable, therefore, to state briefly the objects which the authors had in mind in preparing the present volume and to emphasize that it is the outgrowth of the course in General Botany offered at the University of Missouri and its content has been influenced by many other than the authors.

For most students who take it, the elementary course in Botany is the only formal work in biological science they ever do. We have, therefore, attempted to present the fundamental biological principles rather than to lay the foundation for professional botany. This accounts for the inclusion of some material not strictly botanical in nature and the omission of some items which should be included in a course for the preparation of students intending to specialize in Botany.

In addition to presenting the fundamental biological principles we have tried to illustrate by concrete examples the aim of science and the scientific method. The popular conceptions of what science tries to do, of the way in which scientific knowledge accumulates and of the nature of hypothesis and scientific law are frequently erroneous. Science attempts to describe and relate to one another observable facts. Its conclusions are always tentative, subject to revision on the discovery of new facts not in harmony with the generalizations previously made. Scientific knowledge accumulates slowly and is rarely complete and free from error. It does not spring full formed from the mind of any individual. Natural laws are generalizations or summaries of observed facts; not inviolate pronouncements which nature obeys. The results of science have been of incalculable benefit to mankind, but there are limitations to science: both its advantages and limitations should be recognized. The failure to appreciate the true nature of science has caused much misunderstanding which need not be detailed here. A college course in biological science should give the student

a correct idea of the true nature of the aim of science, its methods of work, and the value and limitations of its results.

Finally we have attempted within the limitations of this book to acquaint the student with the variety and extent of the living world as illustrated in the plant kingdom.

The first portion of the book is devoted to the fundamental physiological processes in living things, and the structures which make them possible, as illustrated primarily by the seed plant. This section leads naturally to a general consideration of life and death, and the origin of life, which in turn carries on to the second section which begins with the bacteria and yeasts. The second section of the book is intended to acquaint the student with the variety and extent of the plant kingdom; to offer opportunity to illustrate in other forms the fundamental principles developed by the earlier discussion of the seed plant; to present the process of reproduction with its relation to the life cycle of organisms; and to furnish the material for a discussion of inheritance and evolution. It should be emphasized that the series of plants selected for this portion of the book and the order in which they are arranged are not intended to present any evolutionary sequence. The fungi have been considered first because of the intimate connection between them and the theory of spontaneous generation and because of the new principles of physiology which they illustrate. The fern is considered before the moss because of the clearer demonstration of alternation of generations given by its life history.

A list of reference books, which must necessarily be incomplete, is included in the Appendix.

We have made free use of the many excellent textbooks available on botany and allied subjects and our indebtedness should be expressed individually to the authors if we could locate exactly in all cases the sources of the ideas or special examples drawn from them. Valuable criticisms and suggestions were made by Dr. C. E. Allen, University of Wisconsin; Dr. Donald B. Anderson, North Carolina State College; Dr. Carl Deuber, Yale University; Dr. R. A. Harper, Columbia University; Dr. E. J. Kraus, University of Chicago; Dr. W. E. Maneval, University of Missouri; Dr. L. C. Petry, Cornell University; and Mr. Albert Saeger, Kansas City Junior College.

Acknowledgment for illustrations from various publications or from unpublished photographs generously supplied is made in the

body of the text. Our particular thanks are due Miss Coral Fleenor, Biological Artist at the University of Missouri, who made most of the original illustrations, and Miss Gertrude J. Bishop, Mr. E. E. Naylor, Mr. R. E. Zirkle and Mr. Neville Todd, students or instructors in the University of Missouri, who are responsible for the balance.

William J. Robbins,
Harold W. Rickett.

May, 1929

TO THE STUDENT

The questions at the end of the book are designed to help you test for yourself your own mastery of the subject. They afford a means by which you can know whether or not you have assimilated the information given in the text. If you can answer the questions in your own words without referring to the text, you have gained something from your study. The questions do not, however, exhaust the list of possible questions. You should try to formulate questions for yourselves, questions which you think a book on Botany ought to answer.

The majority of the questions are answered in the text. Some require a little reasoning based on the facts presented in the text. A few presuppose some knowledge derived from other sources.

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CHAPTER I

The Fundamental Structure of Plants

There are many different kinds of plants; and the differences between them are often great. An oak tree does not resemble a moss, nor is a mushroom like a rose bush. Yet they have some things in common. For example, every plant (and every animal) thus far examined has been found to be composed of one or more units called *cells*.

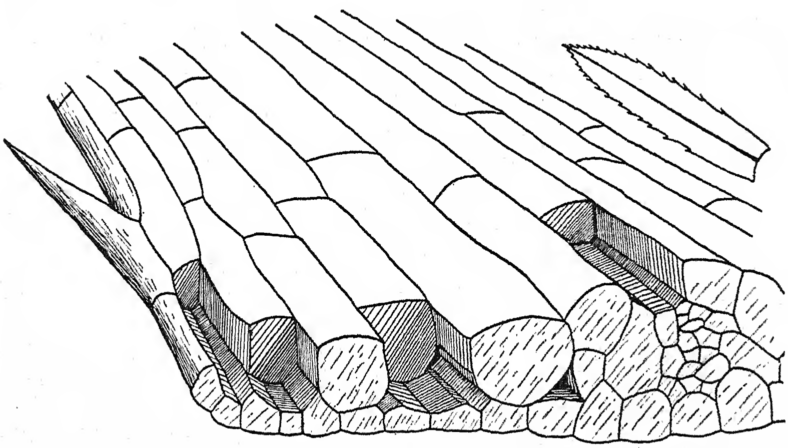


Fig. 1. A portion of a leaf of *Elodea* cut so as to show the cells of which it is made. In the upper right corner is an outline of an entire *Elodea* leaf about 3× natural size.

1. A Plant Cell.—One type of plant cell, which we may select for description, is a box-like structure, the sides, ends, top and bottom of the box being composed of a thin firm layer called the *cell wall*.[1] This wall is usually transparent, so that the contents can be seen through it. The green color of leaves, the purple color of the grape, the various colors of flowers are due to the contents of cells showing through their transparent walls. Inside a living cell, sometimes lining the walls only, sometimes also extending in strands across

[1] The wall of plant cells is composed of various chemical substances, chief of which in most common plants is cellulose.

the cavity, and sometimes almost filling the cavity, is a grayish, slightly granular, liquid or jelly-like material called the *protoplasm*. Enclosed by the protoplasm are spaces or *vacuoles* filled with cell sap, which is water containing dissolved substances (for example, sugar) and finely divided suspended material. Water permeates all parts of the cell, including the protoplasm. Sometimes a red, purple, or blue pigment is dissolved in the cell sap. Frequently there is one large central vacuole.

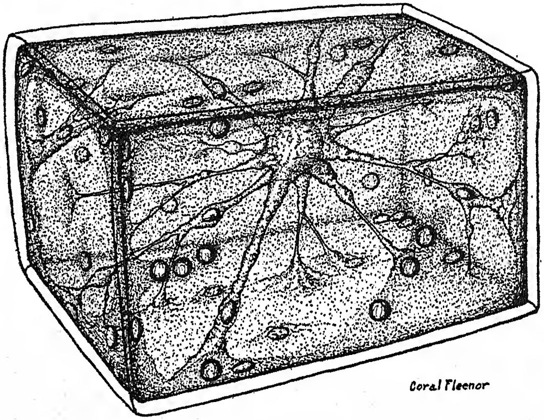


Fig. 2. A semi-diagrammatic drawing of a plant cell to show its three-dimensional character. The nucleus is in the center, surrounded by cytoplasm, from which cytoplasmic strands extend through the central vacuole to the layer of cytoplasm which lines the cell wall. Chloroplasts are embedded in the cytoplasm.

2. **The Protoplasm and its Parts.**—The protoplasm is composed of visibly distinct parts. One of these is a more or less spherical body called the *nucleus* (plural, *nuclei*). This may be near the center of the cell, near one end, or against one side. That part of the protoplasm which is not nucleus is known as *cytoplasm*. It frequently shows a streaming motion, for example a circulation or rotation, within the cell. The nucleus, too, may change its position in the cell, but its movement is much slower than that of the cytoplasm. The nucleus is always entirely surrounded by cytoplasm. Sometimes the nucleus lies in the center of the cell, in the vacuole; but there it is surrounded by a thin layer of cytoplasm, which is connected by delicate strands with the cytoplasm lining the cell walls. The nucleus often seems to be in the vacuole, without any envelope of cytoplasm; but this is an optical illusion;

such a nucleus is really surrounded by cytoplasm, which lines the transparent cell wall through which one is looking and which therefore one does not see.

Some parts of the cytoplasm may be distinctly different from the rest. There are often bodies called *plastids*, usually somewhat smaller than the nucleus and frequently shaped like bi-convex

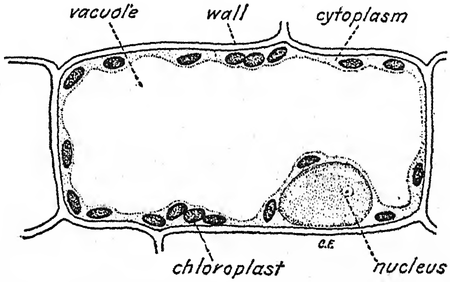


FIG. 3. An optical section through a cell from an *Elodea* leaf.

lenses. Some of these are colored and are called *chromoplasts*, some are colorless *leucoplasts*. The most important of the colored ones are the green ones, which are known as *chloroplasts;* others are yellowish or reddish-brown.[2]

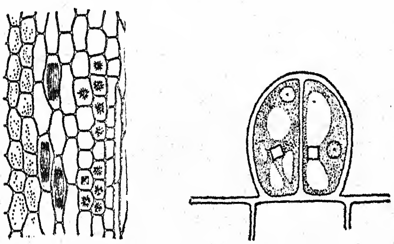


FIG. 4. Left, section through cells of a fallen leaf of the Virginia creeper showing crystals in cells. Right, a two-celled gland on the leaf of potato; each cell contains a single crystal. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

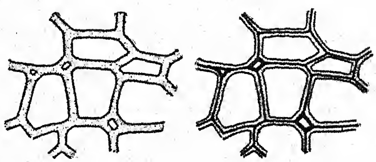


FIG. 5. Sections through plant cells showing the walls only. Left, middle lamella not shown; wall appears common to two cells. Right, middle lamella shown in black.

Other parts of the protoplasm are given names for convenience in referring to specific places, even though they may not be visibly distinct when the protoplasm is examined under the microscope.

[2] The term chromoplast is limited by some authors to the yellow or red plastids, instead of including all colored plastids.

Thus the plasma membrane is that part of the cytoplasm which lies next to the cell wall; the vacuolar membrane is the part of the cytoplasm next to the vacuole; the nuclear membrane is the outer layer of the nucleus. Starch grains or protein granules, crystals, oil drops and granules of pigment may also be included in the contents of a cell. They are collectively called *inclusions*. The living contents of one cell, organized and arranged as they are in the normal cell, are frequently referred to as the *protoplast*.

3. **The Cell Wall.**—The cell wall encloses [3] and protects the

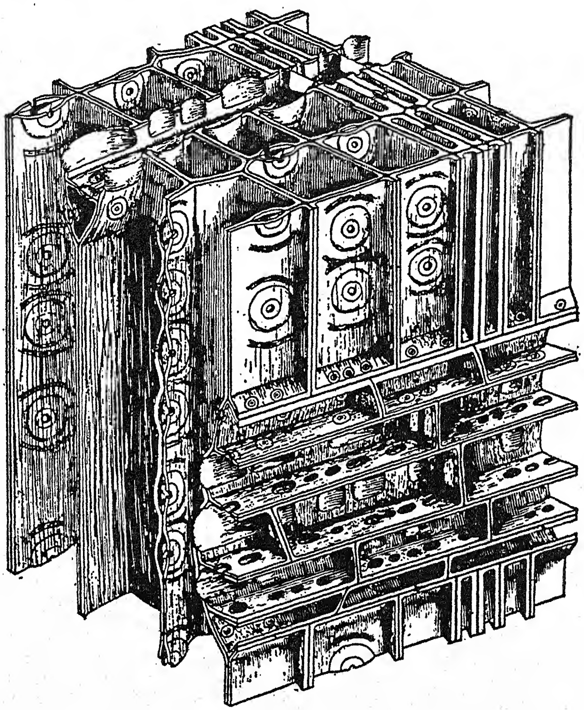


FIG. 6. A bit of white pine wood showing how cell walls may form a structural framework. The walls in this plant are pitted. The middle lamella appears as a black line. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

[3] The protoplasts of some cells have been found to be connected by extremely fine strands of cytoplasm which extend through very minute pores in the cell wall. These fine strands are called plasmodesma. Special technique is usually necessary to demonstrate them, and we do not know how generally they occur. If they are universally present, then the protoplasm in a many-celled plant is really a connected mass, imperfectly separated into bits by the cell walls.

contents of the cell and forms the structural framework of the plant, the wall of each cell being cemented, so to speak, to its neighbors by its outer layer. The fused outer layers of two adjacent cells compose the *middle lamella*,[4] which is common to both cells. This, however, is often invisible unless specially stained; two adjoining protoplasts may seem to be separated by one wall which is common to both of them and in which no layers are to be seen.

The cell wall is formed by the protoplasm but is not itself alive. The protoplasm is the living portion of the cell. Both cytoplasm

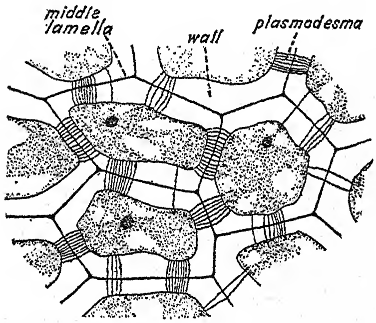


FIG. 7. Plasmodesma in the seed of the persimmon, *Diospyros.* (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

and nucleus are essential for continued life. We may cut a cell into two parts such that one part contains nucleus and cytoplasm while the other part contains only cytoplasm. If either part continues to live, it is always that which contains both nucleus and cytoplasm. We never find a nucleus without surrounding cytoplasm, although sometimes the latter is very small in amount.

A cell may have all of the above mentioned parts and some which have not been mentioned; or some may be lacking. Some cells have no walls and consist only of naked masses of protoplasm.[5]

[4] The formation of the middle lamella is described on p. 107. It is usually composed of substances which differ in chemical composition from those which make up the rest of the cell wall. One of the substances is calcium pectate. Sometimes, as in over-ripe mealy apples, the middle lamella dissolves away and leaves cells or groups of cells separate; this is what causes an over-ripe apple to feel granular on the tongue.

[5] In fact the term cell is used in different ways in Biology. It may mean a cell wall and the space enclosed by it. This space may be occupied by gases or water or by some visible material. If the visible material includes protoplasm, there may be one or more than one nucleus. It may designate also a single nucleus with its

4. Shapes of Cells.—While the cell described above is a box-like structure, not all plant cells have walls which are square or rec-

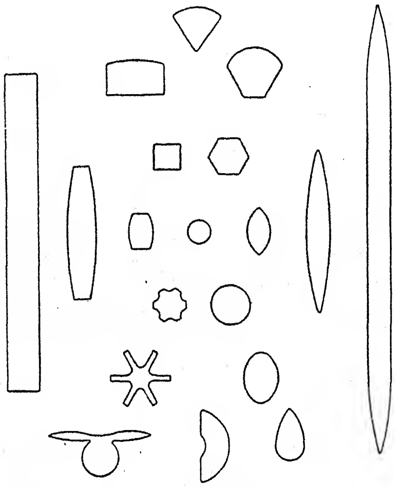


Fig. 8. Generalized drawings of optical sections through the principal forms of plant cells, all of which are derivable by differential growth from the spherical form in the center. (From Ganong, *The Living Plant*, Henry Holt & Co.)

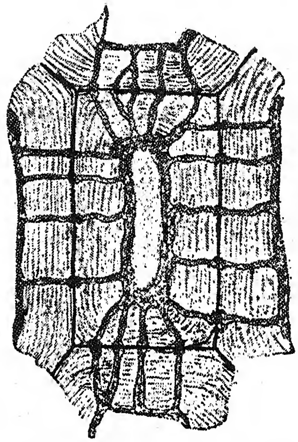


Fig. 9. Section through a cell and parts of four others, from the interior of the nut of the ivory palm, showing the walls immensely thickened by the deposition of layers of cellulose, through which run canals. (From Ganong, *The Living Plant*, Henry Holt & Co.)

tangular. Some cells are barrel-shaped, some are spheres, some are cylinders, and some have irregular shapes which cannot be described by any geometrical figure. Thin slices or *sections* of cells (under the microscope we see optical sections) may have such a variety of shapes as those illustrated in Fig. 8. Cells differ very greatly also in the thickness of their walls. The walls of some cells are curiously marked by pits of various forms or by rings or spirals (see Fig. 6 and Fig. 36).

surrounding cytoplasm when the cell wall is lacking or when it encloses protoplasm containing more than one nucleus. In which of these ways the term is used can be determined generally from the context. The term will not be used in this book for a cell wall and the space enclosed by it if the latter contains protoplasm with more than one nucleus. In such cases each nucleus and surrounding cytoplasm will be considered a cell.

5. Sizes of Cells.—Most cells are too small to be visible to the naked eye. They are usually from 0.015 mm. to 0.065 mm. in diameter. Some are much smaller, measuring 0.001 mm. or less, and others, for example the pith cells of some stems, are a millimeter or more in diameter. One of the largest plant cells is the megagamete of the semi-tropical plant *Zamia* (see Fig. 263), which is about two millimeters in length and one millimeter in thickness. The yolk of an ostrich egg is biologically a single cell, though it measures many centimeters across.

Because cells are so small their discovery was dependent upon the invention of the microscope. Compound microscopes were first made and used by J. and Z. Janssen in 1590.

6. The Microscope and the Discovery of Cells.—Microscopes are now so generally available and the sort of things which they reveal are so commonly known that we may not appreciate the wonder of an instrument which increases the power of the human eye a thousand times or more. "Never did the hope of being able to penetrate the great secret of life appear better founded than at the time when, among other memorable developments of science, it was discovered that objects could be rendered visible on an enlarged scale by the use of glass lenses, and the microscope was invented. These magnifying glasses were expected to yield not only an insight into the minute structure of living beings which is invisible to the naked eye, but also revelations concerning the processes which constitute life in plants and animals. The first discoveries made with the microscope between 1665 and 1700 produced a profound impression on the observers. The Dutch philosopher, Swammerdam, became almost insane at the marvels revealed by his lenses, and at last destroyed his notes, having come to the conclusion that it was a sacrilege to unveil, and thereby profane, what was designated by the Creator to remain hidden from human ken. The observations of Leeuwenhoek (1632–1723) with magnifying glasses formed by melting fine glass threads in a lamp, were for a long time held to be delusions; and it was not until the English observer, Robert Hooke, had confirmed the fact of the existence of the minute organisms seen by Leeuwenhoek in infusions of pepper, and had exhibited them under his microscope in 1667 at a meeting of the Royal Society in London, that doubts as to their actual existence disappeared. Indeed a special document was then drawn up and signed by all of those who were satisfied,

on the evidence of their own eyesight, of the accuracy of the observations; and this clearly shows how greatly people were impressed with the importance of these discoveries." [6]

7. The Discovery of Cells.—Among the things examined microscopically by Robert Hooke were thin slices (*sections*) of bottle cork. He observed that the cork was made of small cavities separated by solid walls. He called these little compartments and their walls *cells*, using the same term as is applied to the enclosed cavities in a honeycomb or in a prison. He observed that the cells of some plants contained what he spoke of as "nutrient juices," but he had no clear idea of their nature. Other men of the same general period, especially Grew, Malpighi and Leeuwenhoek, observed and studied cells as structural parts of plants, but their interest was centered on the wall, not on the cell contents, and on groups of cells rather than on the individual cell.

As microscopes were improved and more examinations of cells were made, a slightly grayish, sticky material, which frequently showed active rotation, was observed in plant cells. The earliest recorded observation of the cytoplasm was made in 1772 by Corti, who referred to it as "sap." Shortly afterwards nuclei were observed; in 1831 Robert Brown reported their general occurrence in plant cells and was impressed with their probable importance.

8. The Cell Theory.—In 1835 Hugo von Mohl laid the foundation of the generalization, later given prominence by Schleiden and Schwann, that the bodies of plants and animals are composed entirely of cells and their products, the cell being the unit of structure and of life-processes and the primary agent of organization.[7] Before this, authors of textbooks had asserted that plants were composed of such things as cellular tissue, tubes, cuticle, bark and woody fibers, without realizing that all of these were composed of cells or products of cells. It is now known that all parts of all living things are composed of cells with their walls and other substances formed by them. The leaf of a tree, the cap of a mushroom, the skin of one's hand, all are composed only of

[6] Kerner, *Natural History of Plants.*

[7] L. W. Sharp says in his *Introduction to Cytology:* "It is said that Schleiden, while dining with Schwann, discussed with him some of his ideas regarding cells in plants, which he had been studying in his laboratory. Schwann had been making similar observations on animals, and after the meal the two went to Schwann's laboratory, where they came to the conclusion that cells are fundamentally alike in both kingdoms."

cells and their products. The bone of an animal is a solid substance with comparatively few cavities containing protoplasm; but it was formed by living protoplasm which encased itself with this solid material, just as the cells of many plants encase themselves with rigid cell walls and thus become what we call wood. The generalization made by von Mohl and later by Schleiden and Schwann, together with later modifications, is known as the *cell theory*,[8] and is the key to much of our knowledge of plants and animals. All structures, all activities are thought of in terms of the structures and activities of cells; the structures and activities of an entire plant are the sums of the structures and activities of the individual cells of which it is composed.

The significance of the protoplasm, however, as the seat of life phenomena was not recognized by the discoverers of cells or by the founders of the cell theory. In 1835 Felix Dujardin described the protoplasm of lower animals, under the name of "sarcode," as a substance with the properties of life. In 1846 von Mohl applied the name "protoplasma" to a similar substance in plant cells, and Nägeli and A. Payen in the same year recognized the importance of protoplasm as the vehicle for the vital activity of the cell. As the result of his own observations and those of others, Cohn, in 1850, concluded that the "sarcode" of the animal and the "protoplasma" of the plant are essentially similar substances and Schultze in 1861 summarized the facts in the statement that the units of organization in living things are masses of protoplasm and that this substance is essentially similar in all living organisms. The great English zoölogist Huxley, in an essay in 1868, called general attention to the *protoplasm as the physical basis of life*. The statement that the protoplasm is the physical basis of life means that the activities of the organism result from the activities of the protoplasm. As I write on the sheet of paper before me, as you read these works, what does the writing or the reading? You may be inclined to answer, "I do it" or "You do it." But anyone acquainted with biological facts says that the protoplasm in the cells of which you and I are made is the place where the activities originate which we call writing and reading. In the

[8] The *cell theory* states that all living organisms are composed entirely of cells and products of cells; that all the activities of living organisms are activities of cells; and that cells originate only from pre-existing cells. A cell, in the sense taken by the cell theory, is an individual mass of protoplasm containing a nucleus.

same way the pleasing shape, the brilliant color, the delightful odor of a flower are the results of the activities of the protoplasm contained in its cells. The structure, the products, the activities of living things result from the activities of the protoplasm.

The protoplasm is therefore of preëminent importance. We might expect that, since it is responsible for such varied and numerous accomplishments, it would appear very complicated, at least as complicated as the insides of a watch, which can only keep time. On the contrary it is disappointingly and surprisingly unimpressive in appearance. Physically it resembles either a dilute or a concentrated and jelly-like solution of gelatine. It is somewhat mucilaginous and elastic.[9] It is quite unstable, changing readily from a jelly-like to a liquid condition, or *vice versa*, and easily coagulating.[10]

The slow development of our acquaintance with the cell and its parts and with their significance illustrates the method by which knowledge accumulates in Science. Our knowledge is never complete, and perhaps never will be. We are like the blind men who examined the elephant. Each of us finds only part of the truth and, just as they did, each of us often concludes that the part he has found represents all of it. Just as they did, we may

[9] Chemically the protoplasm is exceeding complex. It appears to be composed chiefly of compounds called nucleoproteids, which contain the elements carbon, nitrogen, oxygen, hydrogen, and phosphorus, and which have large and complex ultimate particles or molecules.

[10] Our ideas of the physical structure of the protoplasm have undergone a long and interesting development. Brücke (1861) considered the protoplasm to be a firm contractile framework steeped in fluid. Fromman (1865) and others later saw in the protoplasm a reticulum or fine network of living substances which holds a fluid and granules in its meshes. Velten (1873–76) stated that the protoplasm is composed of fine twisted fibers bathed by a fluid. Bütschli (1882) considered the protoplasm to be constructed like an emulsion or foam. He thought it consisted of minute droplets of a liquid suspended in another continuous liquid. At present some consider the structure of the protoplasm to be that of an emulsoid colloid. Substances in the colloidal state consist essentially of ultra-microscopic particles (larger than the molecules in a true solution and smaller than particles in a suspension) suspended in a liquid. An emulsoid colloid has liquid particles. This idea of the structure of the protoplasm is a modification of Bütschli's conception. Others picture the protoplasm as consisting of long tenuous interlacing fibers which are microscopically invisible. This has been called the brush heap structure and is evidently a return to the conception of Velten. These changing ideas represent the results of different and improved methods of examination, or advancement in our knowledge of the minute structure of non-living things which resemble protoplasm in physical properties.

permit our imaginations to interpret the truth we find into something which is more or less incorrect. Almost 200 years elapsed between the discovery of cells and the realization that they are

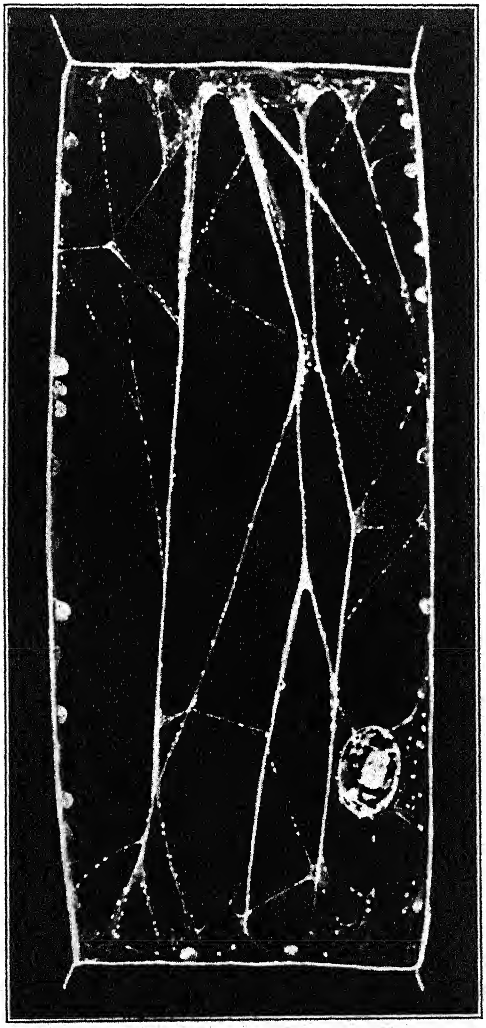


Fig. 10. Cell of *Momordica* with numerous protoplasmic strands extending through the central vacuole, as seen against a black background. (From Heidenhain, *Plasma und Zelle*, Gustav Fischer, Jena.)

the units of structure and activity and that the protoplasm of the cell is the living part of the cell. No single individual was responsible for the information we now have. It is the result of the accumulated contributions, fragmentary and frequently partially in error, of many men. Even now we know that our knowledge of the cell and of the protoplasm is incomplete, and we are still seeking additional information regarding it.

CHAPTER II

Absorption of Water and Dissolved Material

Most living things contain large amounts of water. If we place a freshly cut plant, for instance a corn plant, in an oven heated to 100° C., the water it contains is vaporized, and the plant loses about four-fifths of its weight. What is left, the dry matter, is composed of such things as the cell walls, sugar, starch, oil, the solid material of the protoplasm and mineral materials. In fact, so large a part of a living thing is water that it has been said that if we could see the water in a plant or animal instead of the solid material we would think of living things as made of water held together by a little solid material, instead of solid material containing water.

9. Importance of Water.—This water is indispensable for the maintenance of life. Animals die from lack of water and so do plants. It is not necessary, in order to harm a plant, to withhold water until it is completely dried. Even a small reduction in the total amount of water contained in a plant may be sufficient to interfere with its growth, and a further small decrease may kill it. Some plants or parts of plants, however, are quite resistant to desiccation and remain alive even though their water content is reduced to a small percentage. Living seeds frequently contain but 5 or 6 per cent water; some mosses may be air-dried and yet remain alive, and the same is true of a number of other plants, for example a small fern (*Polypodium polypodioides*) found growing attached to trees in the southern United States. So intimately is water connected with life that it is almost impossible for us to imagine living things inhabiting a place lacking water. The first question which we ask, when it is suggested that there are living things on planets other than the earth, is: "Have we any evidence for the presence of water on that planet?"

Why should water be so important for life? We probably do not know the complete answer to that question. But we do know some of the reasons why water is important. Materials must dissolve in water if they are to enter the cells of a plant or move

from one cell to another. There are no holes in the cell wall large enough to permit solid particles to enter; and though the protoplasm of a cell without a wall may flow around a solid particle and engulf it, even so the particle is still in a sense outside of the protoplasm.

Water is important not only as a solvent but also as a medium in which may occur the numerous and varied chemical reactions which go on in living protoplasm, and which are so important in vital processes. Dry materials do not combine with one another so readily as they do when they are moist or in solution; for example iron rust, which results from a combination of iron and the oxygen of the air, forms most readily in a moist atmosphere.

Water serves also as a nutrient material, for it unites with other substances so as to form important foods; this will be described later.

Water seems to be important in another way, because partial desiccation, the degree varying with the organism and its condition, causes death. The partial desiccation probably causes some detrimental change in the character of the substances which comprise the protoplasm.

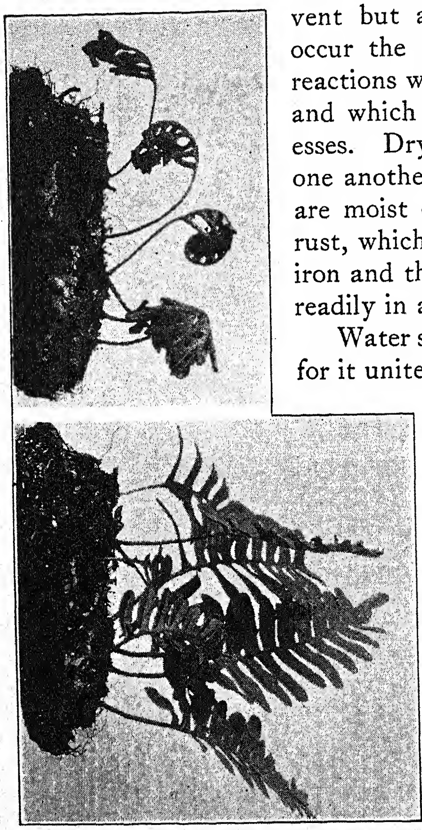


FIG. 11. An epiphytic fern, *Polypodium polypodioides*, which remains alive when air-dried. Above, air-dried; below, after immersion in water for half an hour.

10. Water and Turgidity.—Water also helps to keep living tissues rigid or turgid. It may seem strange to you that a substance so liquid as water can make anything stiff. Yet a hose full of water is decidedly more rigid than an empty hose, and a limp balloon becomes stiff when blown up with gas. In much the same way as the water presses against the wall of a hose and stiffens it, water absorbed by a protoplast presses against the cell walls and stiffens the cell and so a whole piece of tender

plant tissue. If we allow a strip of potato tuber to lie on a table for an hour or so, water evaporates from it, just as water evaprates from a moist piece of cloth. As the water content of the potato decreases, the piece, which was stiff, becomes limber. If we put it into water before it dries enough to die, it will once more become stiff or rigid. The effect of immersion in a salt solution or sugar solution of sufficient concentration is like that produced when the potato is allowed to dry on the table. If we place one strip cut from a potato tuber in water and another piece in a 10 per cent salt or sugar solution, the first one will remain stiff or become stiffer and the second will become limber.

The changes in stiffness are due to changes in the water content of the protoplasts and not to changes in the water content of the cell wall or of the spaces between the cells. This can be demonstrated by surrounding a thin slice of potato tuber tissue with salt solution while we watch it through the microscope. The protoplasm, which touches the wall while the slice is immersed in water, shrinks away from the wall when it is mounted in the salt solution.

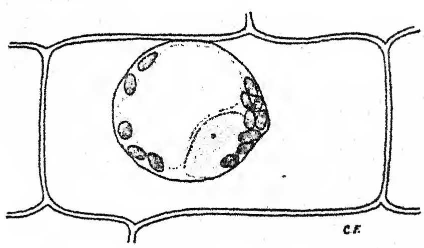


FIG. 12. A plasmolyzed *Elodea* cell. The space between the wall and the cytoplasm is occupied by the plasmolyzing solution.

This phenomenon is called *plasmolysis*. If we return the plasmolyzed cells to fresh water, we can see the protoplast swell until it once more occupies the entire space within the cell wall. The cell is then said to be in a condition of *turgor*.

The protoplast, swelled by the water which it has absorbed, presses against the cell wall, stretching it somewhat if it is thin. The pressure which is developed in this way by plant cells may be considerable. It usually amounts to from four to six atmospheres (60–90 pounds per square inch). Tender toadstools and seedlings break their way through stiff ground, roots of trees have been observed to lift stones weighing a ton or more, a growing squash

has been known to raise a weight of 5,000 pounds. In spite of these great pressures cells do not usually burst, because within the plant the pressure of one protoplast is balanced by neighboring

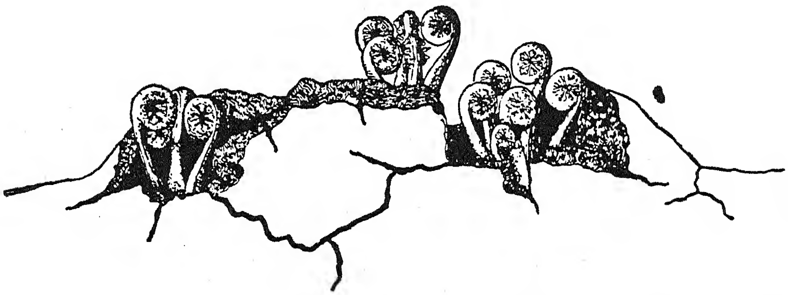


FIG. 13. Young fronds of the Ostrich fern, *Onoclea Struthiopteris*, pushing through a side-walk. (Courtesy of G. E. Stone; from the Popular Science Monthly.)

protoplasts and in the cells on the surface or around air cavities the pressure is distributed over many tiny individual walls each supported by other walls not exposed to the air. Sometimes, however, the pressure becomes so large, and the swelling and change in shape of the cells so great, that the cells are torn apart from one another. This is what happens when growing fruits and vegetables split open during periods of rainy weather. If placed in pure water some cells, for example those of pollen grains, absorb so much water that they burst.

The ability of the protoplast to absorb water is more or less peculiar to its living condition. As a rule a tissue does not absorb as much water when dead as while it was alive. If ten grams of potato tuber tissue are killed by heat or by 50 per cent alcohol and placed in pure water, and ten grams of living potato tuber tissue are placed in pure water, the killed potato tissue loses about one-fifth of its original weight, while the living tissue gains about one-fifth of its weight. The difference between the dead and the living tissue may amount to four grams or more. Because of this decrease in the power of the dead protoplast to absorb water, the pressure in each cell is decreased, and dead tissue is usually limp and pliable even after it has lain for hours in pure water, unless its walls are thick enough to maintain its rigidity.

The cell varies in its ability to absorb and retain water. Not only death and strong salt solutions, but temperature, light,

dissolved materials in dilute solutions, and many other things may affect the amount of water which a cell absorbs and retains.

These are *facts* about the absorption of water by cells which have been repeatedly observed and which anyone can confirm by repeating the experiments. The *explanation* of these facts—the answers to the question "Why do they occur?"—is another matter. Much that happens in water absorption by living cells can be explained by physical and chemical laws; and it is probable that, if we knew more about the protoplast and more about the way in which certain types of non-living things act when they absorb water, we could explain all of the facts. *Osmosis* and *imbibition* seem to be the chief processes concerned in the absorption of water. To explain what we mean by these terms we must review certain facts of physics and chemistry.

11. **Diffusion and Osmosis.**—The particles of a gas have the power of distributing themselves uniformly in any space in which

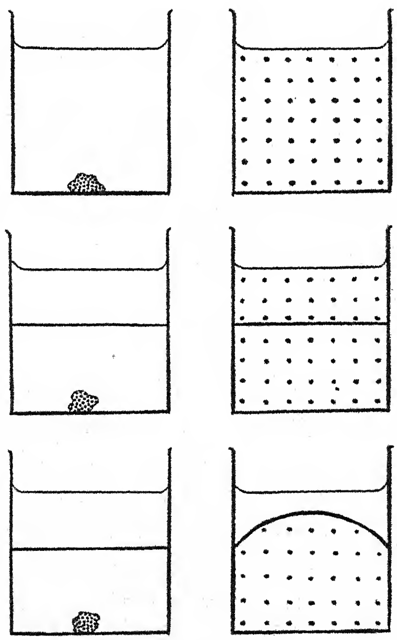


Fig. 14. Above, diagrams to show the result of diffusion of a substance in water; center, result of diffusion through a permeable membrane (osmosis); below, result of diffusion through a semi-permeable membrane (osmosis with the development of osmotic pressure). The molecules of the solid are represented by dots.

they may be enclosed. This is because the ultimate particles (molecules) of the gas are in continuous motion and spread from those places where they are more numerous to those where they are less numerous. This process is called *diffusion*. The molecules of liquids also move, and when a liquid stands in an open vessel some of the particles move off into the air, and the liquid evaporates. The particles of most solids move very little under ordinary circumstances, but if the solid is dissolved in a liquid such as water the movement of its molecules can be readily demonstrated. Thus if we place a lump of sugar in a glass of water it dissolves and the molecules of the sugar move through the water until they are uniformly distributed. This takes place without stirring the solution, without convection currents or any other mechanical mixing of the sugar and water, and is essentially due to the power of movement of the sugar molecules. This also we call diffusion. If a membrane through which both water and sugar can diffuse (a *permeable membrane*) is placed above the dissolving lump of sugar, the sugar molecules diffuse through the membrane, and the final result is the same as though there were no membrane there. The sugar is uniformly distributed through the liquid both above and below the membrane. We call the diffusion of any substance through any membrane *osmosis*.[1] If a lump of sugar is placed in the water below the permeable membrane and a lump of salt in the water above the membrane, the sugar osmoses up and the salt down. This shows that each substance diffuses independently of other substances, the direction of diffusion being from the place where there is more of it per unit volume to the place where there is less of it per unit volume.

12. Osmotic Pressure.—Not all membranes, however, are permeable. Water diffuses readily through a membrane made of a pig's bladder or a membrane of copper ferrocyanide, but sugar does not. A membrane through which some of the constituents of a solution but not others diffuse is called a *semi-permeable* or differentially permeable membrane. Most membranes of importance in biology are permeable to water but more or less impermeable to dissolved material. Such a semi-permeable membrane, for example one made from a pig's bladder, may be arranged in a vessel so that a sugar solution is below it and pure water above it.

[1] The term osmosis is limited by some authors to the diffusion of water through a semi-permeable membrane.

This membrane permits the water but not the sugar to diffuse through it. Under such circumstances more water molecules strike the membrane from above where the pure water is and fewer water molecules strike the membrane from below where there is some sugar present. More water goes down than up and water accumulates on the lower side of the membrane. This accumulation results in the development of a pressure which we name *osmotic pressure*.[2] This is evidently but a special case of the general law of diffusion. Each substance diffuses from the place where there is more of it per unit volume to the place where there is less of it per unit volume. There is more water per unit volume in pure water than in a sugar solution and therefore the water diffuses into the sugar solution. The semi-permeable membrane prevents the sugar from diffusing into the water and so equalizing the concentration of water and sugar on the two sides of the membrane. We may generalize from this and say that, whenever two solutions which differ in concentration[3] of dissolved material (it is customary to speak of the concentration of dissolved material rather than of that of the water which does the dissolving) are separated by a semi-permeable membrane, water will accumulate on that side of the membrane where the greater concentration of dissolved material is found. So if we take a sac made of a semi-permeable membrane and filled with a 10 per cent sugar solution and lay it in a 5 per cent sugar solution, water will osmose into the sac and the sac will swell. If we fill it with a 5 per cent solution and place it in a

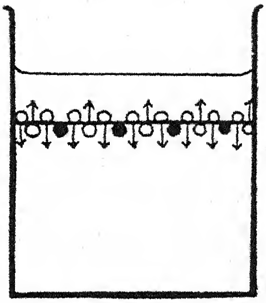


FIG. 15. Diagram of osmosis through a semi-permeable membrane. The molecules of the solid striking the membrane are represented by black dots and those of the water by white circles.

[2] Osmotic pressure is defined here as a hydrostatic pressure which results when two solutions differing in concentration of dissolved material are separated by a semi-permeable membrane. This is probably the most satisfactory use of the term for biologists. Physicists and chemists also use it for the pressure which develops in non-aqueous systems (a rubber bag filled with alcohol and immersed in carbon bisulfide) and for the force of diffusion which exists whether a membrane is present or absent. The explanation given in the text for the development of osmotic pressure is not complete but is probably of more value to the beginning student than a more complete and complex one would be.

[3] *Not* density, which means weight per unit volume.

10 per cent solution, water will osmose out of the sac and it will shrink.

The living cell acts very much as though it were an osmotic chamber, the outer portion of the protoplast (the plasma membrane) acting as a semi-permeable membrane. Most cell walls are quite permeable to dissolved material. When we surround the cell with pure water or dilute solutions (containing less dissolved materials per unit volume than the cell sap) water is absorbed; and when we surround it with concentrated solutions (containing presumably more dissolved material per unit volume than the cell sap) the protoplast loses water and shrinks. Decreases in the concentration of sugar or other dissolved material in the cell sap lower the ability of the cell to absorb water and on the other hand an increase in the concentration of dissolved material in the cell sap increases the ability of the cell to absorb water.

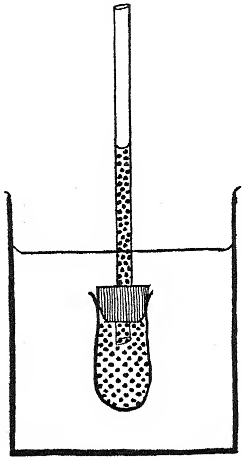


FIG. 16. An osmoscope. The sac is made of a semi-permeable membrane and contains a sugar solution. Water enters the sac and increases the volume of the solution, which rises in the glass tube and develops a pressure.

13. **Imbibition.**—Another somewhat different process helps us to understand how a cell absorbs water and develops pressure. If we lay a piece of dry gelatin in water, it will swell to several times its original size. This swelling is due to the absorption of water. We can dry the gelatin and it then returns to its original form. The gelatin is a solid or semi-solid material, with no inner space filled with a solution like that in an osmotic sac. The water absorbed by the gelatin enters between the particles of which the piece of gelatin is made, and separates them.[4] When solid or semi-solid bodies absorb water and swell we call the phenomenon *imbibition*. It is this kind of absorption which causes a piece of dry wood to swell. The walls of the cells of which the wood is composed imbibe water. The absorption of water by cell walls,

[4] The forces concerned in imbibition are not well understood. We may picture a bit of gelatin as composed of particles which may be aggregations of molecules or large compound molecules. These particles are sometimes called micellae. They stick together or cohere. Diffusion, aided perhaps by capillarity and surface tension forces, causes water to enter between the micellae and forces them apart.

and by the solid or semi-solid parts of cells, such as the cytoplasm and the plastids, probably occurs in much the same way as in a piece of gelatin. It is difficult, however, to see how imbibition can account for the absorption of water by an entire cell which has a large central vacuole. Here osmosis would seem to be a more probable explanation. In fact, both osmosis and imbibition are probably concerned in water absorption by cells, their relative importance varying with the kind of cell concerned.

14. **Absorption of Dissolved Material.**—Plant cells absorb, in addition to water, dissolved material of various kinds, for example salts, gases in solution and so on. Some of the materials absorbed by plant cells are necessary for their life, others are decidedly harmful, still others are indifferent in their effect. Some dissolved materials are absorbed readily and accumulate in the cells in considerable amounts, others are absorbed slowly and accumulate to a very slight degree. The death of cells affects the absorption and retention of dissolved material as well as of water. Pigments and sugar, which do not readily come out of living cells, do so rapidly after the cells are killed. Other types of dissolved materials which are not absorbed by living cells may quickly penetrate dead ones. Light, temperature and other environmental factors influence the absorption of dissolved materials.

15. **Explanation of the Absorption of Dissolved Materials.**—To explain all of the facts regarding the absorption of dissolved materials by plant cells is a very difficult matter. The plasma membrane to which we have referred earlier in discussing the absorption of water is evidently not permeable only to water because it permits dissolved material, at least of some kinds, to diffuse through it. We must assume that its permeability is different for different substances and varies from time to time for the same substance. We understand that diffusion, if the membrane is permeable, will equalize the concentration of dissolved material on the two sides of the membrane, but in many cases a dissolved material may accumulate in the cell in far greater concentrations than in the solution surrounding the cells. Iodine is present in sea water at a concentration of 1 part per million, yet enough accumulates in some of the seaweeds to make it commercially feasible to recover the iodine from the ash left when the seaweeds are burned. Leaves of a water plant, *Elodea*, may be placed in a dilute solution of a blue dye, methylene blue, and other leaves in a dilute solution of

another blue dye, nigrosin. Microscopic examination after a few hours shows that the methylene blue accumulates within the protoplasts in sufficient quantity to make the cells a deep blue, while the nigrosin does not. Why does the absorption of iodine and of methylene blue not cease when the concentrations of these substances inside and outside the cells are the same, as would be expected from our knowledge of diffusion? In some cases the accumulation of a substance in the cell can be explained by its transformation into an insoluble or indiffusible form after entering the cell. This transformation results in a removal of the substance as such from the cell sap, and a consequent reduction in the concentration in the cell of the substance, which permits more to diffuse in. Organic acids and colloidal protein in the cell sap combine with the methylene blue to form a new compound, also blue, which is indiffusible. In other cases the dissolved material accumulates in its unchanged form in the cell sap, and we are not able to explain the reasons for such a condition.

16. The Cell Theory and Physics and Chemistry.—This discussion illustrates that the attempt to discover how plant tissue absorbs water and dissolved material leads us inevitably to the cell, the unit of structure and activity in all living things. To understand such an everyday affair as the stiffening of a wilted slice of potato which has been laid in water necessitates a knowledge of the response of the individual cells of which the slice of potato is made. So it is with attempts to elucidate other activities of living things. Each illustrates the fundamental importance of the cell theory.

The discussion shows also how the scientist tries to explain the activities of living things in terms of the responses of non-living things, which are summarized in the laws of physics and chemistry. Often the explanation of the activities of living things by what we now know of the responses of non-living things (physical and chemical laws as now developed) is incomplete. This is true of the absorption of water and dissolved material by plant cells. But, although diffusion, osmosis and the development of osmotic pressure may not explain all of the phenomena which occur in the absorption of water and of dissolved material, they do help us understand some of them, for example why potato tuber tissue should lose water and become limp in a 10 per cent salt solution and absorb water and become turgid in pure water. We may

perhaps have a better explanation at some future time when our knowledge of the cell, and of the way in which certain non-living things act, is more complete. In the meantime a partial explanation is better than none.

17. **Summary.**—We may summarize as follows: Living cells contain much water, chiefly in the protoplasts. This water is a necessity for life. It dissolves the materials which are absorbed and moved in the plant, it is a medium for the occurrence of chemical reactions, it is an actual nutrient, it gives tender plant parts rigidity. Its absorption produces considerable pressure within the cell. This pressure is important in growth and in enabling tender plants to do work. The absorption of water by living cells can be imitated in many respects by osmotic cells or by such materials as gelatin, neither of which are living systems or materials. Diffusion is concerned also in the absorption of dissolved materials by plant cells, though here too we are not sure whether the cell acts in the process more like an osmotic sac or more like a piece of gelatin or similar material.

CHAPTER III

THE ROOT

MOST familiar plants have a root system in the soil and stems and leaves above it; and the water which is so important for the life of the plant enters the plant by the roots, and through them is moved to the other parts of the plant. The root is therefore an extremely important organ,[1] even though it is hidden in the soil and so does not strike the attention of the average person.

18. **Importance of Roots.**—The roots are important to the life of the plant in several ways. In addition to water various dissolved materials enter the plant through the roots; the nature and im-

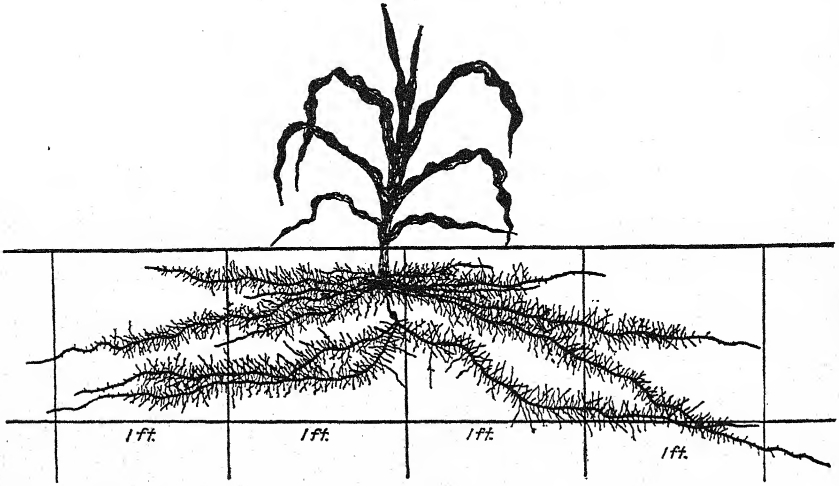


FIG. 17. The root system of Iowa Silver Mine corn 36 days old. (From Weaver's *Root Development of Field Crops*, McGraw Hill Book Co., Inc., New York, N. Y.)

portance of these will be discussed later. Furthermore, many roots, such as the familiar beet, store large amounts of food, which is just as useful to plants as it is to ourselves. And finally, the

[1] The term "organ" is used to refer to a part of a plant or animal whose construction is adapted to a distinct process or group of processes. The roots, stems, and leaves are organs. In addition to the activities peculiar to the organ it engages in others which are common to it and other parts of the plant

root system anchors the whole plant in place and holds the stem in an upright position, thus maintaining the upper parts of the plant in the air and sunlight which they need.

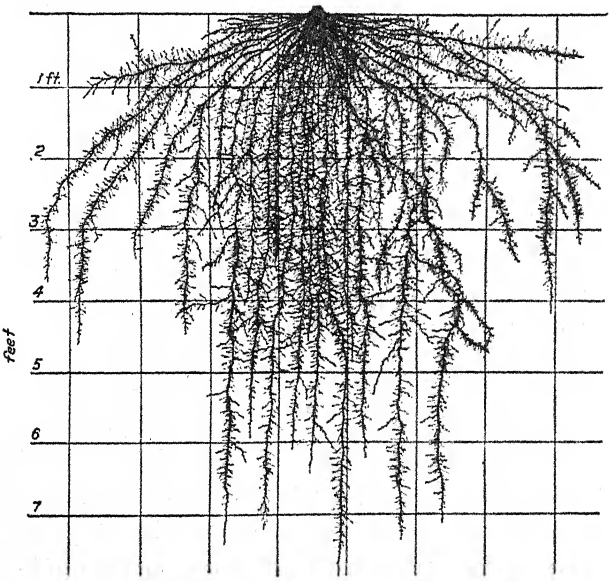


FIG. 18. The root system of a mature corn plant. (From Weaver's *Root Development of Field Crops*, McGraw Hill Book Co., Inc., New York, N. Y.)

19. Extent of Roots.—The roots of an ordinary plant form a much-branched system which is about as extensive as the top. The root system of a mature corn plant extends about 3 feet laterally from the base of the stem and, if the soil permits, from 7 to 7½ feet vertically. The soil in a corn field is nearly filled with corn roots to a depth of from 3 to 3½ feet. The roots of alfalfa commonly penetrate the soil 6 or 8 feet vertically, and have been found 30 feet beneath the surface, and those of the mesquite may grow down 60 feet. Many trees, such as the apple and the poplar, have roots which extend out 50 feet or more from the base of the trunk.

20. The Soil.—The soil [2] in which the root system is located is

[2] The importance of the soil as the substrate in which plants grow is generally recognized. We often refer to it as "Mother Earth." Its complexity is not so generally appreciated. The student would do well to glance through such a textbook as that of Lyon and Buckman, *The Nature and Properties of Soils*, and observe how diverse and how complicated soils actually are.

composed of particles of weathered rocks and of the more or less completely disintegrated bodies of plants and animals (*humus*). Between the particles of solid material are air spaces (unless the soil is saturated with water); covering each particle is a film of

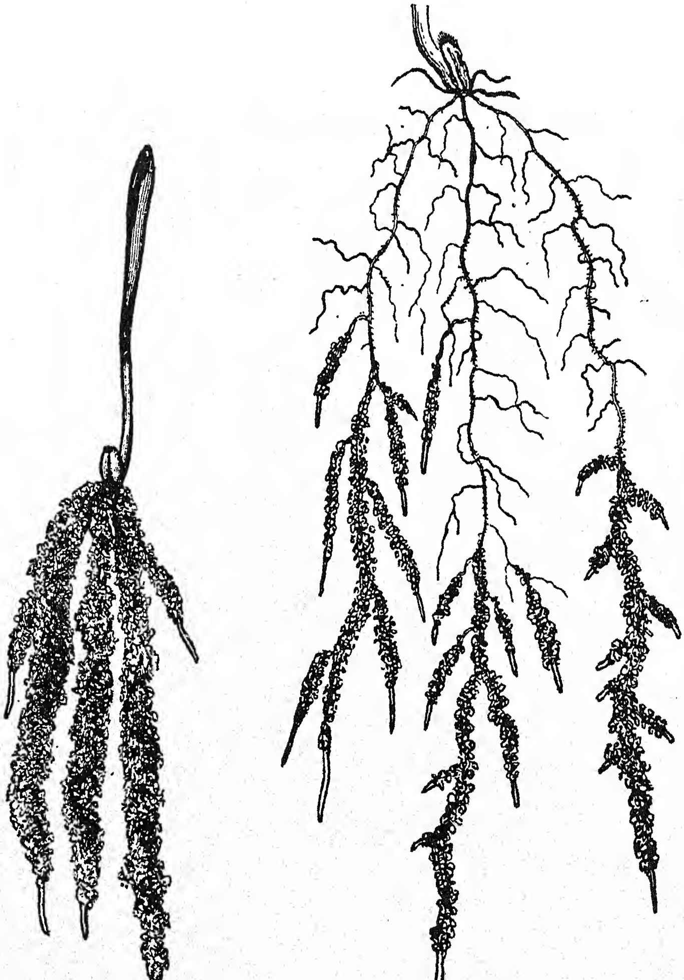


FIG. 19. Left, seedling wheat plant; right, another four weeks older; both lifted carefully from sandy soil. Notice that the root tips are bare and that the sand clings to a short region above the root tips. (From Sachs, *Physiology of Plants;* copyright 1887 by The Macmillan Company. Reprinted by permission.)

water containing dissolved material, which is called the *soil solution*. There are also various small plants and animals in the soil, many of them microscopic in size, and numbering millions per gram of soil.

The root system is in intimate contact with the soil, as can easily be demonstrated by gently pulling up a young seedling growing in loose soil. The soil clings closely to the roots, particu-

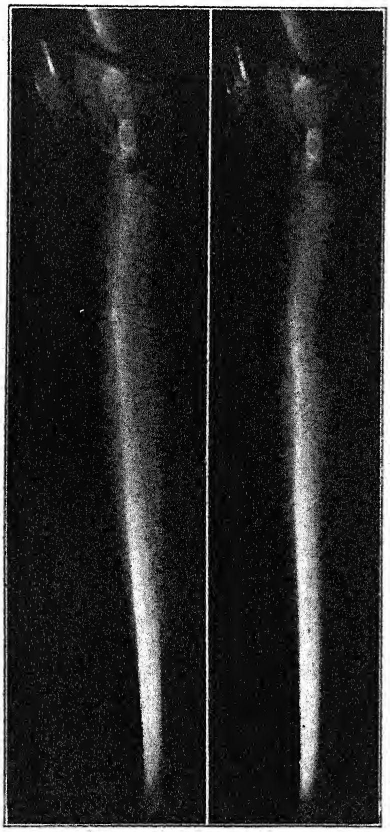


FIG. 20. Root hairs on a young corn root grown in a moist chamber. Left, root photographed immediately after removing from moist chamber; the left-hand side of root was touched lightly with the end of a pencil; notice the effect on the delicate root hairs. Right, same root after two minutes' exposure to the dry laboratory air.

larly to those parts near the root tips. In such regions the particles fall off only as the surface dries.

21. External Structure of Root.—An examination of the external structure of the root shows why this occurs. For this purpose we should use roots which have been grown in moist air and are free of soil, and preferably roots such as those of grass seedlings, which are thin enough to be examined with the low power of the microscope. The tip of the root is smooth and rounded and covered by a thimble-shaped cap of rather loose cells. These cells make up the *root cap*, a structure peculiar to roots. A few millimeters above the tip are innumerable fine hairs which extend out at right angles from the root, unless they have partially dried and collapsed into a tangled mass. These hairs cover only a short region, rarely more than a few centimeters. Microscopic examination shows each root hair to be a finger-like projection from a cell of the outside layer (*epidermis*). Near the tip of the root the hairs are nothing more than bulges of the walls of epidermal cells. Farther back they are longer. Their maximum length varies from a millimeter or less to a centimeter or more, while their diameter is about 0.01 of a millimeter, approximately 1/20th that of a silk thread. The slender, elongated root hair penetrates between the soil particles, its shape being frequently moulded to that of the bits of clay, sand, or humus in the soil. It is the root hairs [3] that are responsible for the clinging of the soil to the region of the root just above the tip, and it is the root hair zone, where such intimate contact with the soil occurs, that absorbs most of the water and dissolved materials.

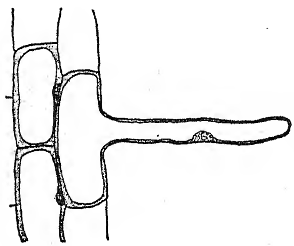


FIG. 21. A single root hair. (From Ganong, *The Living Plant*, Henry Holt & Co.)

The root hairs of most plants live only a few days or weeks, the ones farthest from the tip dying and disintegrating, while new ones are formed next the tip as it elongates and pushes its way through the soil. This continually brings the root hair zone into new portions of the soil. Above the zone of root hairs is the region where branch roots appear; but these sometimes appear in the upper part of the zone of root hairs.

Before we can follow the water and dissolved materials through the root into the stem it is necessary to become familiar with the internal structure of the root in the region of the root hairs. For

[3] The student should be careful not to confuse root hairs with branch roots.

this purpose we use a section cut across the root (a *cross section*) in the vicinity of the root hairs, and a section cut lengthwise (*longitudinal section*) from the tip back through the same region.

22. **Internal Structure of Root.**—The most obvious thing about a cross section of a root is that it is composed of cells. Each cell

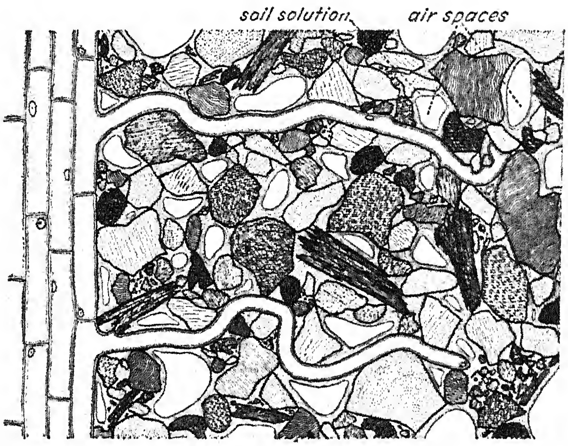


Fig. 22. A diagram to show the relation of the root hairs to the soil particles and soil solution. (Redrawn from Sachs.)

has a wall and sticks to its neighbors. The latter fact is due to the layer common to both cells, the middle lamella. The cells appear almost empty because of their large central vacuoles, but careful examination discloses thin layers of protoplasm lining the walls. The cells are not all alike. Those which have the same general appearance occur together in groups; they are usually alike in their activities as well as in their structure. We call such groups *tissues*. The tissues of the root in the root-hair zone are grouped in three main parts, called the *epidermis*, *cortex*, and *stele*. Each of these parts is composed of one or more tissues.

The outermost layer of cells is the epidermis. Some of the epidermal cells produce root hairs. Each epidermal cells fits tightly against its neighbors, so that there are no holes between them, and whatever enters a root must pass through the epidermal cells, not between them.

Within the epidermis are many rows of cells which appear more or less circular in cross section, and which, therefore, are not in

contact with each other throughout their circumferences; the little spaces between them are filled with air. There are frequently much larger air spaces in this region, as in a buttercup root. The walls of the cells are thin, and they possess no special structural

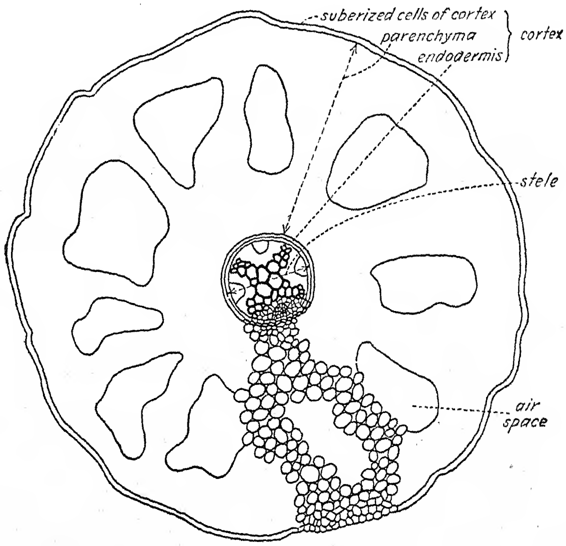


Fig. 23. Diagram of a cross section of a young root of a buttercup, *Ranunculus acris*. Suberization of the outer cells of the cortex has resulted in the epidermis being sloughed off.

modifications. We call them *parenchyma* cells, by which we mean thin-walled cells unspecialized in structure. They occur in many parts of plants, are of various sizes and shapes, and carry on various activities.

The band of parenchyma cells in a root is bounded on the inside by a row of cells of fairly regular shape, often with thick walls.[4] This row is called the *endodermis*. The parenchyma in this part of the root, and the endodermis, together make up what we call the cortex. Within the cortex lies the central cylinder or stele. The outer layer of the stele, lying just within the endodermis, is named the *pericycle*. Within the pericycle and touching it at

[4] Sometimes only the radial walls are thickened, sometimes the radial walls and the inner tangential walls. Radial walls are those which coincide with radii of the circle described by the endodermis; tangential walls are walls making tangents to that circle.

several points are groups of cells known collectively as the *primary xylem*. They are thick-walled, usually many-sided in cross section, and empty of visible contents. Many of the xylem cells are larger than the other cells of the stele. In the roots of many kinds

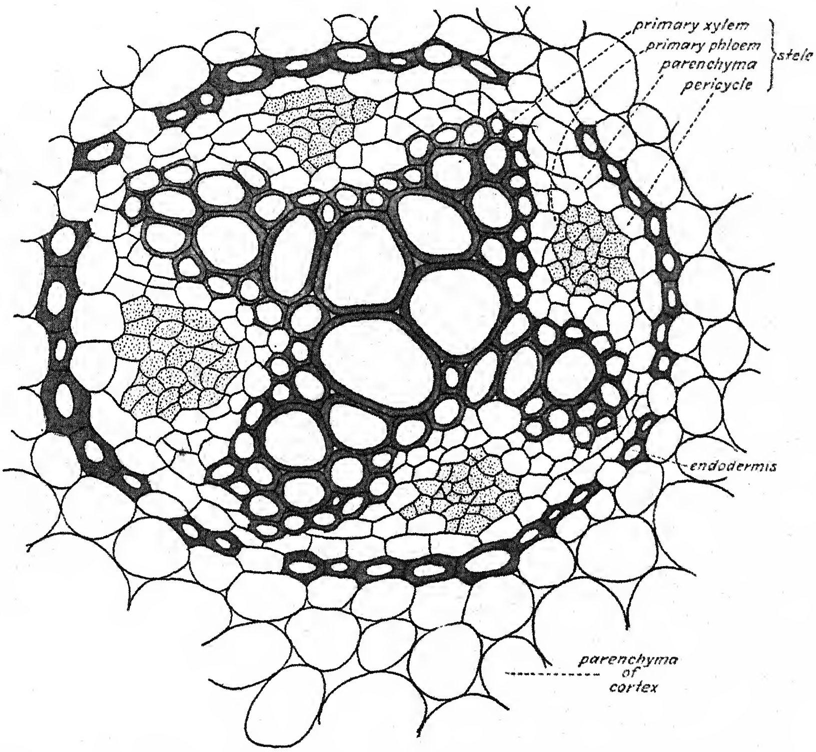


FIG. 24. A cross section of the stele of a young root of the buttercup, *Ranunculus acris*.

of plants these groups of xylem cells meet in the center of the root, so that a cross or star-shaped figure appears in the section. Alternating with the points of the primary xylem are small groups of very small cells, thin-walled and somewhat irregular in shape. These groups are the *primary phloem*. They do not fill the spaces between the arms of the xylem; between them and the xylem are small parenchyma cells. In the older portion of the root some of the latter usually form a growing region known as the *cambium*.

This tissue is more easily understood in a stem, and will be described and discussed in the chapter dealing with that organ.

In a longitudinal section we can observe from the side the appearance of the tissues which we have examined in cross section. The most noticeable facts are the following. Many of the tissues found in the region of the root hairs do not extend to the root tip.

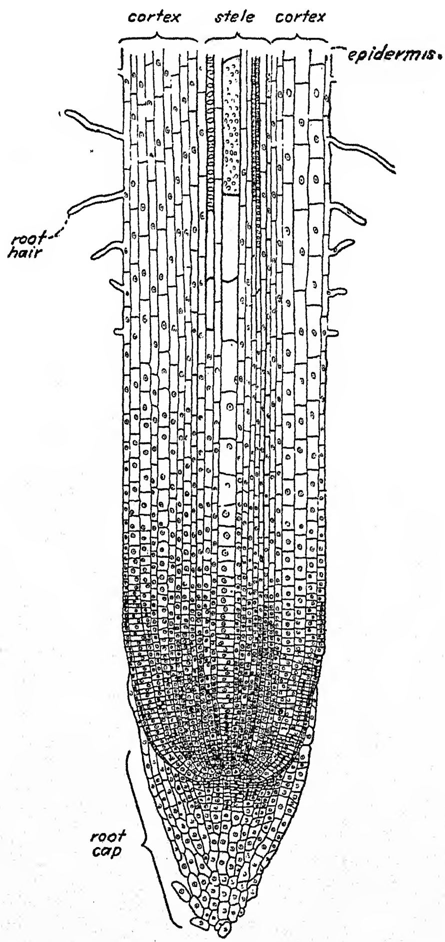


FIG. 25. Longitudinal section of a root tip of corn, *Zea Mays*. The cell walls and nuclei are shown; the cytoplasm and vacuoles are omitted. Notice the simpler construction near the tip. (Reprinted by permission from *Textbook of General Botany* by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

The root is more simply constructed near the tip. The cells are arranged in rows the long way of the root.

The cells of the epidermis, cortex parenchyma, endodermis, pericycle and stele parenchyma are from four to six times as long as they are broad. The xylem and phloem cells are much longer in proportion to their width than any other cells in this region of the root.[5] Most of the xylem cells lack protoplasm; in the living root their cavities are filled with water and materials dissolved in water. Their shape is not dependent upon turgor. Their walls

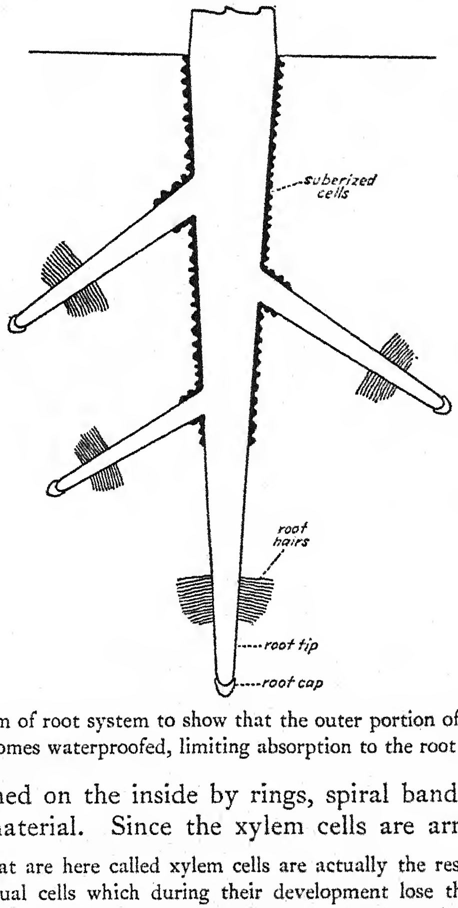


Fig. 26. Diagram of root system to show that the outer portion of the older part of the root becomes waterproofed, limiting absorption to the root hair region.

are strengthened on the inside by rings, spiral bands or networks of cell wall material. Since the xylem cells are arranged end to

[5] Some of what are here called xylem cells are actually the result of the fusion of several individual cells which during their development lose their protoplasmic contents and end walls and thus form a system, much as short pieces of water pipe placed end to end might form a pipe of some length. Each of these structures resulting from the fusion of several cells is called a *vessel* or *trachea* (plural, *tracheae*).

end, as are the other cells in the root, they form a series of tubes which extend up the root. In fact they continue up the stem and out into the leaves, where they form parts of the veins.

The outer walls of the cells of the epidermis in the region of the branch roots may become waterproof, developing a layer of a material called *suberin;* or the epidermis may entirely disappear, the walls of the outer cells of the cortex instead becoming suberized. In still older portions of the root a suberized layer several cells in thickness develops, and forms a waterproof outer portion of the root. This more or less limits the absorption of water and dissolved materials to the root hair zone. The root hairs, besides making possible intimate contact with the soil particles, markedly increase the absorptive area. It has been calculated that normal root hair production increases the absorptive area of the roots of corn five or six times and that of barley about twelve times. Since root hairs increase the absorptive area of the root so greatly, conditions which interfere with their development or which injure them are important in water absorption by the plant. Poor aëration or the presence of certain injurious chemical substances may prevent the formation of a normal number of root hairs; and exposure for a short time to dry air, as may happen in transplanting, kills them.

23. Functions of Cells and Tissues.—It is in the xylem that water and dissolved material absorbed from the soil move. The root hairs absorb water from the soil solution, both osmosis and imbibition being probably concerned. The water then moves through the cortex from cell to cell (not between the cells), through the endodermis and into the xylem, up which it passes to all parts of the plant. Water is absorbed by the root only when the absorptive power of the root hairs exceeds the forces holding water to the soil particles.

Each of the tissues which has been described has more or less particular functions.[6] The epidermis is the primary absorptive

[6] In biology the term function has various meanings and implications. It may refer to any result of the structure or activity (such as the strengthening of the plant or the manufacture of food) of a cell, tissue, organ, or individual. It may be limited to those results which are normal to the structure, or to those which are normal and more or less peculiar to it. It may be used with no implication that the function is of benefit or advantage or it may be limited to those which result advantageously. The term is used in this text for *any result of the normal structure or activity of a cell, tissue, organ, or individual* with no reference to the utility of the result. Those functions which are more or less peculiar to the structure we call *special functions*, those which the structure has in common with others we call *general functions.*

region; the parenchyma of the cortex is a region where food materials such as starch are frequently stored; the endodermis protects the stele and may function in other ways; from the pericycle the branch roots originate; the xylem conducts water and gives the

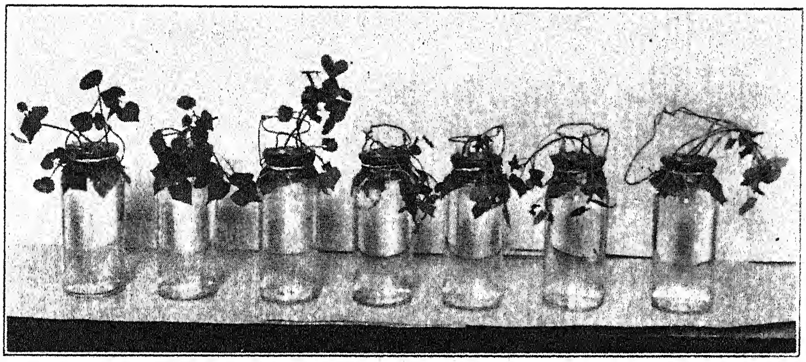


FIG. 27. Plants of buckwheat, *Fagopyrum esculentum*, grown with their roots in tap water. The water was then replaced by salt solutions of various concentrations. The photograph shows the appearance of the plants a few hours after replacing the water by the salt solutions. From left to right the concentrations of salt are: 0.15%, 0.3%, 0.45%, 0.6%, 0.9%, 1.05%, 1.2%. The roots do not absorb sufficient water from the more concentrated salt solutions to prevent wilting.

root toughness; and the phloem conducts dissolved food materials. The air spaces between the cells, present particularly in the cortex, provide a ramifying system through which gases may diffuse to and from the cells of the interior tissues.

24. **Adaptation.**—The structure of the cells of which each tissue is composed is often adapted to the function of the tissue. The root hairs formed by the epidermis are admirably fitted by their shape for contact with the soil solution from which they absorb water and dissolved material. Some of the water, in its movement from the soil to the xylem, must pass through the endodermis; the occasional thin-walled cells in the endodermis of some plants occur just opposite the points of the xylem, in those parts of the endodermis nearest to the water conducting system. The xylem vessels are tubes through which water can readily be moved, and they are strengthened by structures (rings, spirals, networks) which are economical of material. The roots, which anchor the plant, are frequently subject to pulls or stretching forces. For

resisting stretching forces the best arrangement of the resistant elements is together as in a rope and not separate as in individual strands; for in the latter arrangement unequal distribution of the stretching force might tear the individual strands one after another. In the root the thick-walled resistant cells (xylem and endodermis) are together in the central part of the root, and not scattered throughout the cortex and epidermis. It would be difficult to plan an organ better adapted than the root to its various functions.

25. **Summary.**—It is evident that the root is a mass of cells each of which functions in various ways. The entire root, therefore, carries on a number of activities, such as absorption, conduction, storage of food, and the like. The various structures of the cells give the root its characteristic form and strength, and explain its usefulness as an anchor for the whole plant. This again illustrates the value of the cell theory in biology; our knowledge of the root is largely dependent upon our knowledge of the structure and activities of the cells of which it is made. The structure of those portions of the root which have been described thus far may be summarized as follows:

- Root
  - External
    - Root cap
    - Tip region free of root hairs
    - Root hair region
    - Branch root region
  - Internal in zone of root hairs
    - Epidermis
    - Cortex
      - Parenchyma
      - Endodermis
    - Stele
      - Pericycle
      - Phloem
      - Xylem
      - Parenchyma

CHAPTER IV

The Stem

We have seen that water enters the root of a plant. Thence it passes up the stem and so into the leaves, branches, and other aërial parts. As we shall see later, much water diffuses from the leaves out into the air. It follows, then, that in a land plant under normal circumstances there is a stream of water continually passing up through the stem.

26. Importance of Stem.—It is a simple matter to demonstrate that water does actually rise through the stem. If the roots of a plant, or the lower end of the stem, are placed in water colored with a dye, the dye may be found after a suitable time in the upper parts of the stem. Moreover it will rise to the top of the stem in far less time than would be required for the dye to diffuse up through the cells. Hence there must be actually a current of liquid passing up the stem. The experiment shows also that materials dissolved in the water pass upwards with the water.

If we study a cross section of the stem near its upper end, we find that the dye has not risen through all parts of the stem, but only in small groups or bundles of cells which occupy a ring in the section fairly close to the surface. Obviously, then, there are certain cells in this position whose special function is the *conduction* of water and dissolved materials. The water of which we have been speaking, and the substances dissolved in it, come from the soil, by way of the root hairs and other epidermal cells near the root tip.

Sugar and other food materials also are moved in the stem. The roots of a plant, since they are living and growing organs, are obtaining food, besides water and mineral substances. The source of the food is, as we shall see later, in the green parts of the plant, especially the leaves. It is plain, therefore, that food must be constantly passing down the stem from the leaves to the roots. The same fact is illustrated by the presence of large amounts of food in underground organs such as the enlarged root of a beet or sweet potato. This food also comes from the leaves, and the only way it can have reached the root is through the stem.

Since many stems contain, in some of their cells, chloroplasts, they, like the leaves, *manufacture* food. Of the food made in the leaves and stem of a plant, there is frequently a surplus not immediately consumed by the living cells, and this, as *stored food*, accumulates sometimes in the stem; for example, cane sugar in the stem of the sugar cane. Many stems have underground branches—for instance tubers, like those of the Irish potato—which contain large amounts of stored food.

It is commonly known that green plants will not live very long unless they are exposed to sunlight; indeed, the manufacture of food by leaves depends upon this factor. And of course the leaves, and also flowers and fruits, are kept exposed to sunlight and air by the stem, which in most plants is a more or less rigid organ. The fact, therefore, that a stem *supports* the leaves and flowers as it does is of great importance to the life of the plant. Some plants, for example vines, have pliable stems which require a support of some kind; but most land plants have rigid stems which withstand strong winds and support heavy weights of branches, leaves and fruits. The rigidity of these stems is of equal significance with the toughness of the root in maintaining the position of the plant.

Like other parts of the plant the stem is a growing organ; it is from the stem that new leaves, flowers and fruits are produced. Some plants live for many years and periodically shed their leaves and fruits and grow new ones.

We may summarize these functions of a stem as follows: Conduction of water and dissolved materials from soil to leaves and other aërial parts; conduction of food from the leaves to other parts of the plant; manufacture of food; storage of food; support of aërial parts; growth.

Besides these functions, which, with the exception of growth, are not common to all parts of plants, the living cells of the stem, of course, perform other activities common to all living cells, such as respiration—without which none of the special activities would long continue.

27. External Structure.—Externally considered, the stem with its branches is the most familiar part of the plant—the only living part of plants we see outdoors during the winter months. Commonly the stem is erect, cylindrical, tapering gradually in thickness towards the top. It is terminated by a bud which consists of the

tip of the stem surrounded by young leaves or by young leaves and modified leaves. The young parts of the stem bear leaves, and often also flowers and fruits. The leaves are usually arranged on the stem in a definite way, varying with the kind of plant—they

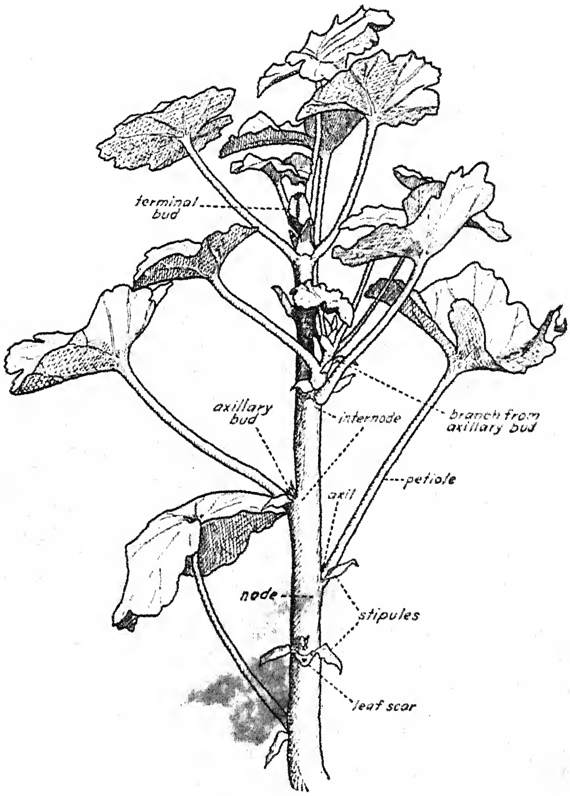


FIG. 28. External structure of a typical dicotyledonous stem. Portion of a geranium plant.

may arise singly, in pairs, or in circles; the points at which the leaves are attached are known as *nodes*, and the regions between the nodes as *internodes*. Sometimes the nodes are swollen or marked by a distinct line. Many stems form branches, themselves replicas of the main stem; branches usually originate in the *axils* of the leaves—that is, in the angles where the leaves meet the stem; and consequently the number and arrangement of branches is

connected with the number and arrangement of leaves. Young stems are tender and green; as they become older they frequently become hard and rough and dark colored on the surface. Stems which live for more than one year become woody, thick, and very rigid.

We can separate stems more or less completely into two groups, the *herbaceous* stems, which are green and tender and which usually are killed when subjected to frost or severe drought, and the *woody* stems, which are hard and tough and which for the most part live through the winter. An herbaceous stem may become woody with age. Most stems may be grouped also as *dicotyledonous* or *monocotyledonous*. The distinction between these two stem types will become clear as we proceed with the discussion of their structure.

28. Internal Structure—Young Dicotyledonous Stem.—We will consider the internal structure of a typical young dicotyledonous stem, for example that of the castor bean or sunflower plant.

As in the root, the internal structure is simplest near the tip. There the cells are all much alike and about of equal size in all dimensions. But a cross section made a few centimeters back of the tip of such a stem reveals a structure which resembles that of a root in the region of root hairs.[1] We can group the tissues into the same three general regions, epidermis, cortex, and stele. And many of the cells of the stem resemble closely those of the root and go by the same names. Their arrangement within the three main regions is, however, very different.

The central portion of the stele, and therefore of the stem, is composed, not of heavy-walled xylem cells, as is usually the case in a root, but of thin-walled parenchyma cells, similar to those which occupy the cortex of a root. This central part of the stele is known as the *pith*. The pith cells have thin, peripheral layers of cytoplasm and large central vacuoles, and sometimes they contain stored food. Frequently the pith cells die and go to pieces, leaving a hollow in their place.

The xylem (primary xylem) of the stem, instead of being in the form of a cross or star, is distributed in *several small groups*[2] near

[1] The structure of the stem nearer the tip and the structure of the stem farther from the tip where increase in diameter occurs through the activity of the cambium are discussed in the chapter on growth.

[2] In some stems, for instance the young twigs of common trees, the xylem has the form of a cylinder surrounding the pith; the phloem is a second cylinder outside the xylem.

the outer part of the stele. The phloem (primary phloem) also is in small patches (as is the root phloem); but these patches, instead of alternating with the patches of xylem (as in roots), are opposite them, on the side towards the cortex; the two together, xylem and

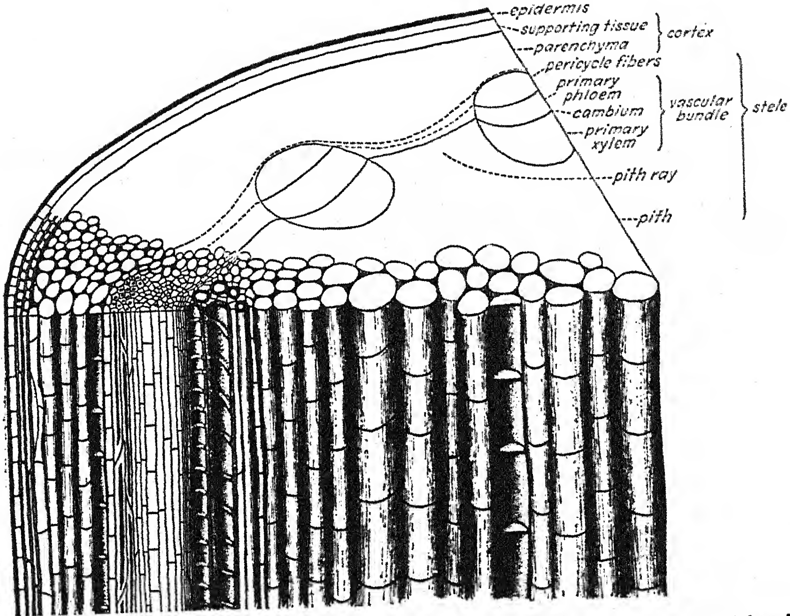


FIG. 29. Portion of a young sunflower stem showing the tissues in cross and longitudinal section.

phloem, with a few parenchyma cells between, form a *vascular bundle.* There is a ring of these in the cross section—a cylinder, of course, in the stem. Between adjacent bundles in the ring lie parenchyma cells similar to those of the pith. The regions between bundles, made up of these parenchyma cells, are called *pith rays,* or *medullary rays.* Since they are composed of exactly the same sort of cells as are found in the pith, there is no definite boundary between these two regions. For convenience we consider the pith to be limited by an imaginary line touching the parts of the vascular bundles nearest the center of the stem.

Some of the parenchyma cells in this part of the stem are *embryonic* (that is, capable of the formation of new cells). This is true of the small parenchyma cells which lie between the xylem

and phloem. They form what is known as the *cambium*, which is a tissue which continues to give rise to new cells and consequently causes the stem or root to become thicker. The details of this will

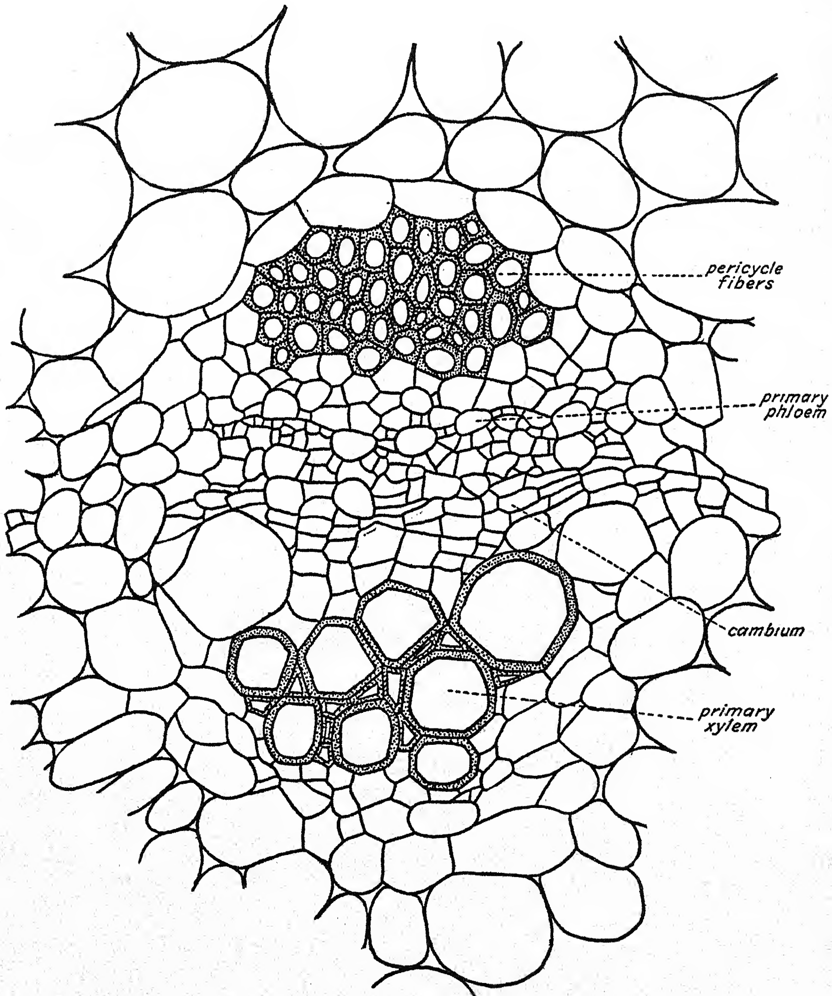


FIG. 30. A cross section of a single fibro-vascular bundle of a young sunflower stem.

be considered later. Cambium cells may be recognized easily by their small size and regular arrangement. They are rectangular and arranged in rows radiating from the inside of the circle; this

is because they are formed continually by successive *cell divisions* in planes parallel to the surface of the stem. Cambium also develops in the parenchyma cells of the pith rays which are adjacent to the cambium of the bundles. Thus the cambium comes to be a continuous cylinder extending completely around the stem in the outer part of the stele. The cambium within the bundles is known as the *fascicular* cambium, that in the pith rays as the *interfascicular*.

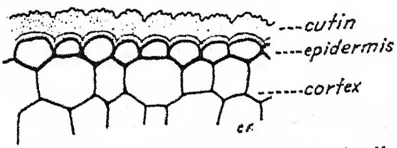


FIG. 31. The cutin on the outer walls of the epidermal cells of a stem of ivy.

The pericycle of the stele and the endodermis of the cortex are in most stems not clearly distinguishable; so that it is difficult to see just where stele ends and cortex begins—especially since most of the cortex is composed of parenchyma cells very like those of the pith rays of the stele. When neither pericycle nor endodermis is distinguishable we may assume that the boundary of the stele is just outside the ring of vascular bundles. In many stems patches of fibers develop in the pericycle opposite each patch of

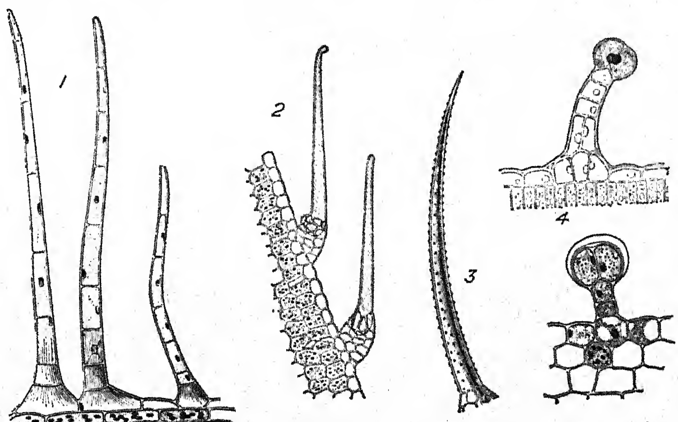


FIG. 32. *1*, three hairs on the chickweed, *Stellaria media*, ×50; *2*, hairs on the stinging nettle, *Urtica dioica*, ×40; *3*, hair from *Echium italicum*, ×20; *4*, two capitate hairs; above, from star thistle, *Centaurea*, ×20; below, from a geranium, *Pelargonium*, ×75. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

primary phloem. They are known as *pericycle fibers.* These patches of pericycle fibers together with the vascular bundles compose the *fibro-vascular bundles.* Most of the cortex, as has already been mentioned, is composed of parenchyma cells; but the cells of its outer layers have walls much thickened, especially on the sides parallel to the epidermis and in the angles; and these cells, therefore, lend rigidity to the stem and are known as *supporting cells.*[3] This tissue is lacking in most roots.

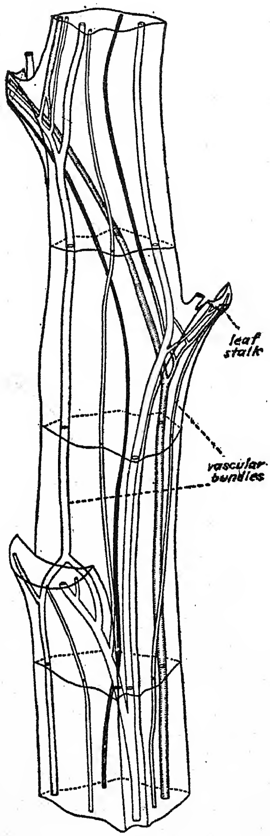


FIG. 33. A diagram of the primary vascular system of the potato, *Solanum tuberosum.* Notice that the bundles are continuous up the stem and into the leaves but that they branch and anastomose. (After Artschwager from Eames and MacDaniels, *Introduction to Plant Anatomy,* McGraw Hill Book Co., Inc., New York, N. Y.)

The epidermis, like that of a root, consists of a single layer of cells. The outer walls of the epidermal cells are often much thickened; and it may be proven by using certain stains that these thick walls contain a different material from that of other cell walls. This is *cutin,* a wax-like substance impermeable to water. The epidermis therefore prevents the escape of water from the stem—whereas at least a part of the epidermis of a root provides a path by which water *enters* the plant from the soil. Some of the epidermal cells of a stem frequently project from the surface and thus form hairs—stem hairs. These hairs may be single-celled or several-celled and on some plants they are stiff and sharp or otherwise repellent to animals, so that the plant may owe to its hairs the fact that it is not eaten by animals. The epidermis of a plant protects the other cells in more ways than one.

In a longitudinal section made through the center of the same part of the stem which we have studied in cross section, the fibro-vascular bundles are seen as two streaks, one on either side near the

[3] Also called *mechanical cells.*

epidermis. They extend almost but not quite to the stem tip. The bundles branch and anastomose, some of the branches extending into the leaves. As in the root most of the cells are longer than they are broad and they are arranged in rows which extend up and down the stem.

The parenchyma cells, which occupy the pith, the medullary rays, and most of the cortex, are only slightly longer than broad. They possess no special peculiarities of structure. They are thin-walled and of various sizes, their shape is determined mostly by the pressure of neighboring cells, and they usually possess a large central vacuole. They may perform a variety of functions, and are not limited by specialization to one or few functions. In the pith and in pith rays they may store food; they also allow substances in solution to diffuse crosswise through the stem. In the cortex they are frequently green (containing chloroplasts) and manufacture food. As already mentioned, some parenchyma cells function in growth by becoming cambium.

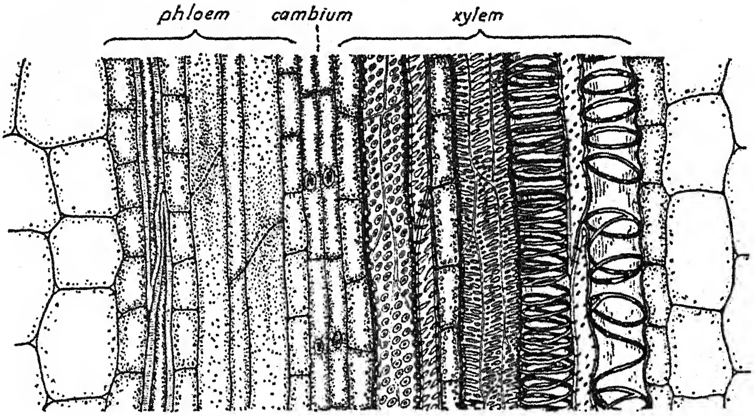


FIG. 34. Longitudinal section of a bundle of a young dicotyledonous stem. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

The xylem, not hitherto considered in detail, is composed of several different kinds of cells. The most conspicuous are large cells with peculiarly thickened walls; in the cavities of these cells passes most of the water that rises in the stem. They have no protoplasmic contents, are more or less circular in cross section, and much elongated in longitudinal section. The walls are thickened

on the inside of the cell by rings, spirals, or ridges, or certain thin places remain in an otherwise uniformly thick wall; whence they are called spiral, annular, scalariform, reticulate or pitted. Some of these have developed from single cells; they are called *tracheids*. Others are formed from several cells in which the end walls have disappeared, which makes long tubes with continuous cavities, the side walls of which are formed from those of several cells joined

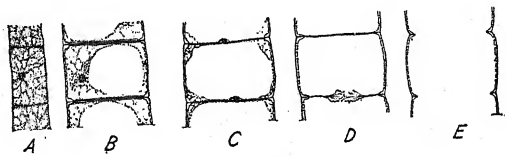


FIG. 35. The formation of a vessel from several cells, the protoplasmic contents and end walls of which disappear. The cells are shown in longitudinal section. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

end to end. These are known as *tracheae* or *vessels*. Since we may hesitate to call a vessel a cell, and since it is sometimes difficult to distinguish without careful and detailed examination between tracheids and vessels, we sometimes use the term *xylem element* in referring to a vessel, tracheid or other morphologic unit of the xylem. Besides vessels and tracheids, *xylem fibers* are present in the xylem. These resemble tracheids but have very small cavities. There are also small *xylem parenchyma* cells among the other kinds.

The phloem also is composed of several sorts of cells. The cells which conduct most of the food are known as *sieve tubes*, because they are elongated and tube-like, and their end walls are perforated with small holes so that a sort of sieve develops between one cell and that above or below (sometimes also in the side walls). They remain thin-walled, are not large in cross section, and their protoplasmic content does not disappear as in vessels. Their nuclei, however, frequently do disappear. Associated with each sieve tube is usually a much smaller elongated cell, called a *companion cell*. Its function is not known, but it is supposed that its nucleus may function with the cytoplasm in the sieve tube. As in the xylem, there are small parenchyma cells mixed with the other kinds. Capping the part of the phloem nearest the cortex there

are the pericycle fibers, which are quite similar to the fibers of the xylem, though frequently even more heavily walled.[4]

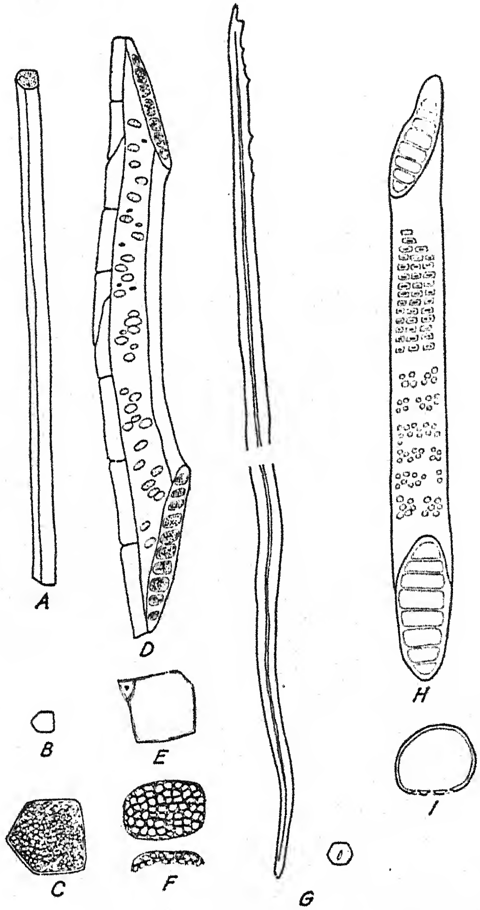


FIG. 36. Sieve tubes, a phloem fiber and a xylem vessel in side view and cross section. *A*, sieve tube from the potato, *Solanum tuberosum; B*, cross section of the same; *C*, an end view of the sieve plate; *D*, sieve tube and companion cells from the tulip tree, *Liriodendron; E*, cross section of the same; *F*, sieve plate enlarged; *G*, phloem fiber from the willow, *Salix nigra*, only two thirds of the cell shown; *H*, vessel from *Liriodendron; I*, cross section of the same. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

[4] The phloem is also called *bast*. The pericycle fibers are frequently called phloem fibers or bast fibers. The xylem and phloem of the root, not previously described in detail, are in general similar in composition to those of the stem.

The supporting tissue of the cortex consists of cells which resemble the fibers of the vascular bundles in having interlocking ends, though, as previously mentioned, their walls are not uniformly thick on all sides. The stem has therefore three distinct groups of cells which strengthen it—the xylem fibers, the pericycle fibers, and the supporting tissue of the cortex.

The epidermal cells are only slightly longer in a longitudinal section than in a cross section. Their characteristic structure has already been discussed.

The lower part of the stem is of course connected with the root. Near the level of the soil there is usually what is called a *transition region.* Root and stem are not separated by a line of division.

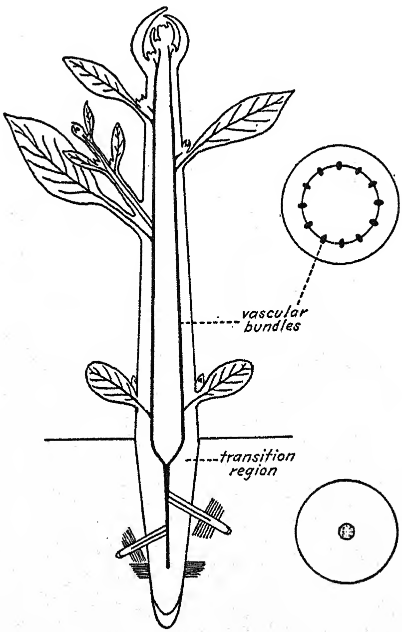


FIG. 37. Diagram of a dicotyledonous plant showing the conductive system. Diagrams of cross sections of the root and stem are shown at the right.

In the transition region the xylem groups of the stem slant in towards the center of the stem and so connect with the star-shaped mass of xylem in the center of the root. The phloem groups diverge sideways so that they come to lie between the xylem groups, like those of the root with which they are joined. There

is therefore a continuous conductive system from bottom to top of a plant, consisting of both xylem (through which water moves and substances dissolved in it) and phloem (through which food moves).

All the tissues outside of the cambium are collectively known as the *bark*. The bark therefore includes phloem, part of the pith ray, the pericycle; all of the cortex; and the epidermis. As the stem becomes older, the epidermis, and frequently also the cortex, may disappear and be replaced by *cork cells*, which form the rough, hard outer surface of a tree.

29. Summary of Structure Dicotyledonous Stem.—The structure of a young dicotyledonous stem a few centimeters from the tip may be summarized as follows:

- Epidermis
- Cortex
  - supporting tissue
  - parenchyma
  - endodermis (often not differentiated)
- Stele
  - pericycle (often not differentiated except the pericycle fibers and these usually included in fibro-vascular bundles)
  - vascular bundles
    - phloem — sieve tubes, parenchyma, companion cells
    - cambium
    - xylem — vessels, tracheids, fibers, parenchyma
  - pith rays (become partly cambium)
  - pith

30. The Monocotyledonous Stem.—The stem that has been described is typical of the young stems of common and familiar plants such as geraniums, sunflowers, beans and trees in which little or no cambial activity has occurred. There are considerable differences in the proportion of the various tissues. There is, however, a large group of plants which have stems of a very different structure. This group includes, besides many other important plants, the great grass family, familiar examples of which are wheat and Indian corn. Since this family is very common and of immense importance to mankind, a knowledge of its structure is desirable. The stem already discussed is characteristic of the group of seed-bearing plants known as the Dicotyledons. The grasses belong to the group known as the Monocotyledons. The meanings of these terms will become clear when the reproduction of these plants is studied.

The corn stem may be used as an example of the monocoty-

ledonous type. In external appearance it is much like other stems, except for the swollen nodes and for the fact that it does not taper very much, but is of nearly uniform thickness throughout its length. In a cross section the most conspicuous difference is the absence of visible differentiation into stele or cortex. The stem is bounded

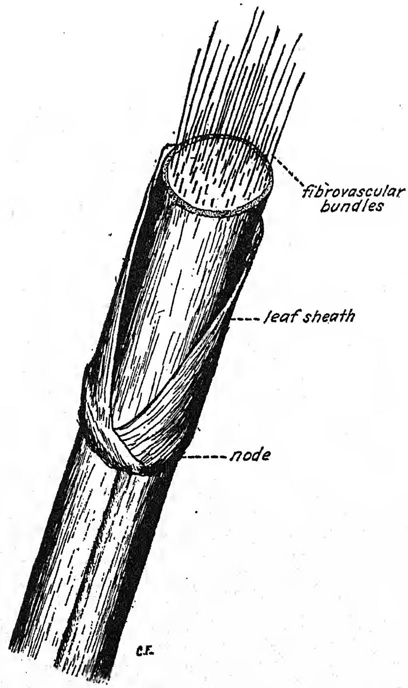


FIG. 38. Vascular bundles dissected out of a corn stem.

by an epidermis, under which lie several layers of thick-walled cells forming a supporting tissue. There are many vascular bundles scattered throughout the stem, the outer ones very near the epidermis; and they are surrounded by parenchyma cells. The parenchyma and supporting tissue are essentially like that in the stem previously studied. The vascular bundles themselves are composed of xylem and phloem as are those of a dicotyledonous stem, but there is no cambium in the bundle (or elsewhere in the stem); and there are certain other differences. The phloem lies in the part of the bundle nearest the epidermis. It is composed entirely of sieve tubes and companion cells, arranged usually in a

very regular manner. As a rule the sieve tubes are eight-sided in cross section; the companion cells are four-sided and four of them are in contact with four of the sides of each sieve tube. The whole

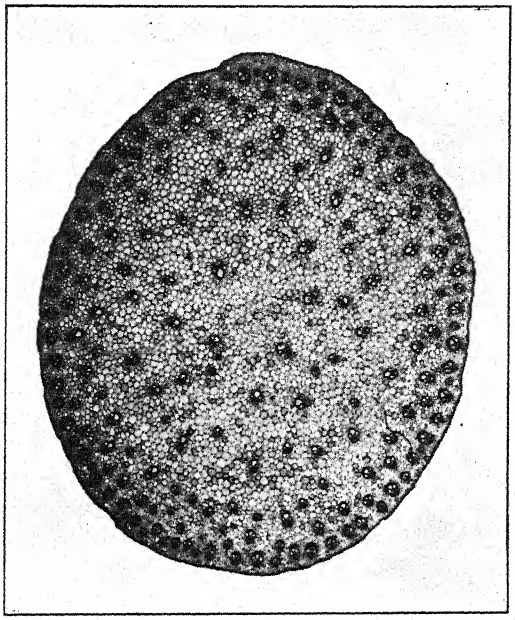


FIG. 39. Photograph of a cross section of a young stem of corn, *Zea Mays*. ×10.

group forms in the section a neat little lattice of cell walls. The xylem lies close to the phloem on the side towards the center of the stem. The most conspicuous things in the xylem are four large xylem elements. Two very large pitted vessels lie on either side and near the phloem. Two additional elements lie between these and further from the phloem; one is usually spiral and the other annular. Surrounding one or both of these latter is often an air space, caused by the pulling away of the surrounding cells. One or both of the two smaller elements may be lacking. Between these four elements are smaller cells, parenchyma and small conducting cells. Surrounding the entire bundle are several layers of thick-walled cells which form what is called the *bundle sheath*. This is often much thickened on the side towards the epidermis. Frequently some crushed cells, the *protophloem*, lie between the bundle sheath and the phloem. Because of the lack of a cambium

the stems of most kinds of monocotyledonous plants do not increase in diameter by the addition of new cells; they become no thicker after all their cells have grown to maturity. There are, however,

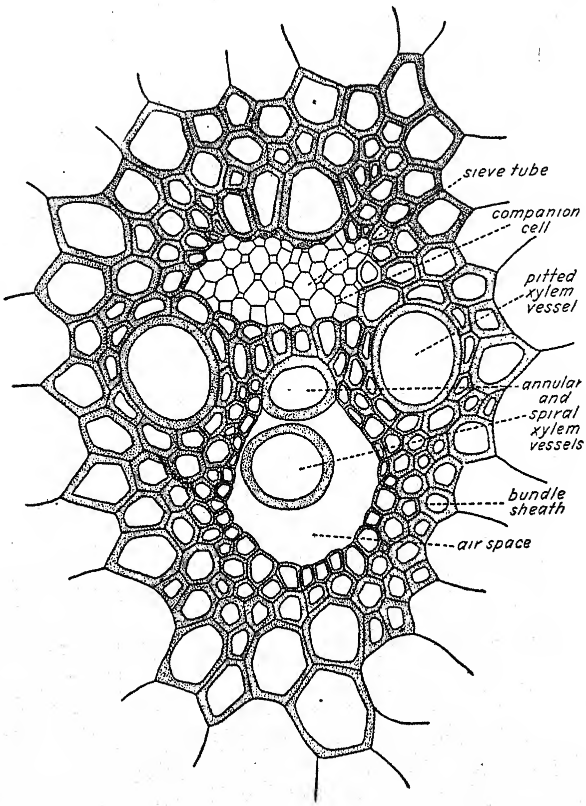


FIG. 40. Cross section of a single fibro-vascular bundle of corn, *Zea Mays*.

exceptions to this—certain monocotyledonous stems have a cambium or a cambium-like tissue.

31. Adaptation of Structure to Function.—The structure of the stem shows many remarkable adaptations to its functions. Mention has been made of the cutinized epidermis which prevents water loss. The relation between the structure of the xylem vessels and tracheids and their function as paths for the movement of water was discussed in connection with the root. Attention might be called to numerous others. The most remarkable of these

adaptations is the correlation which exists between the structure and arrangement of the supporting tissue of the stem and the stresses which it undergoes as a supporting organ.

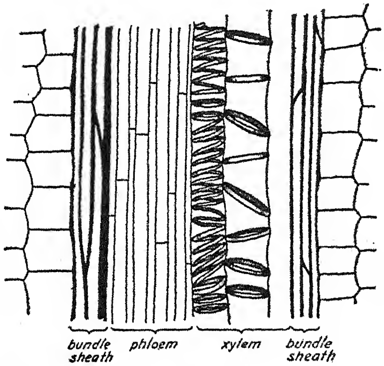


FIG. 41. Longitudinal section through part of a single fibro-vascular bundle of corn, *Zea Mays*. Compare with Fig. 40.

It is a well-known engineering principle that for a given weight of material a hollow column will support more weight (resist greater longitudinal compression) than the same amount of material in the form of a solid rod. The reason for this is simple. The weight of an object resting on the end of a vertical solid rod is rarely distributed uniformly over the entire cross section of the rod. It tilts to one side or the other and the maximum longitudinal compression is exerted on the sides of the rod and the least in the center. We therefore remove the material from the center and place it on the sides, where the maximum compression is exerted, and this produces a hollow column.

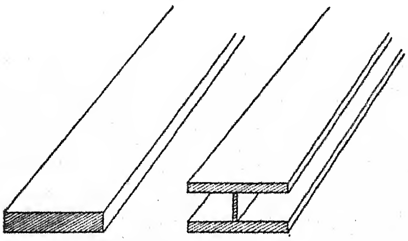


FIG. 42. A solid beam and an I beam made of the same amount of material. The wide portions at the top and bottom of the I beam are the flanges; the connection is the web.

That an I beam will support a greater bending stress than a solid beam made of the same amount of material is also well known. The I beam has two strong parallel flanges with a rather weak web at right angles to them. The reason for this is also easily grasped. If we have a horizontal solid beam supported at one end and weighted at the other, the upper surface will be stretched and the lower compressed. The center of the beam will be distorted least. We therefore take the material from the center of the beam and add it to the upper surface and lower surface where the stresses are greatest. This forms the I beam.

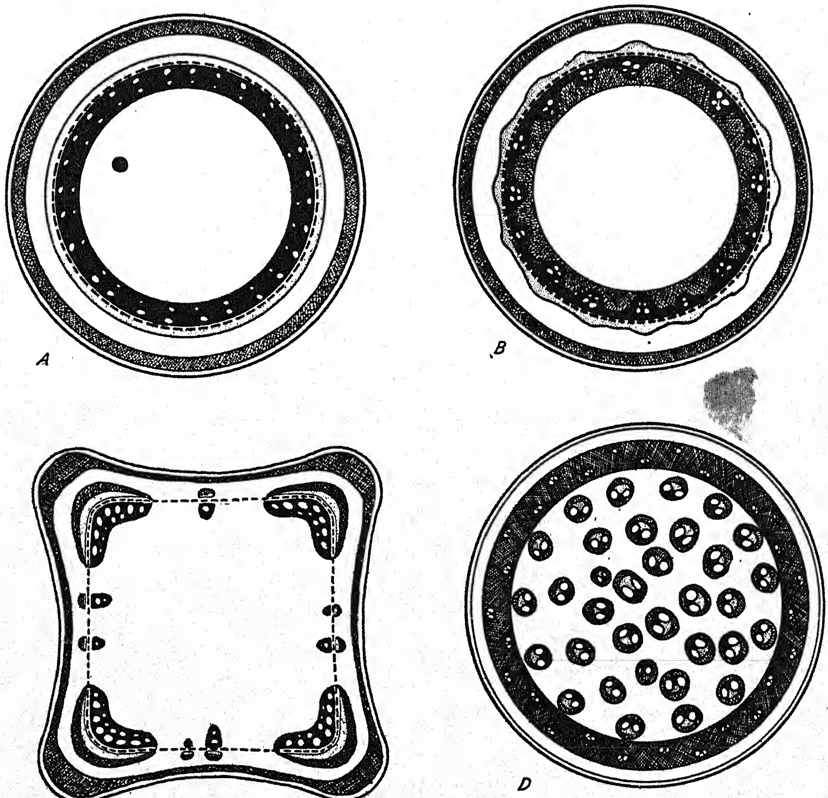


FIG. 43. Diagrams of young stems. The xylem is black with white dots, the phloem is finely stippled, the supporting tissue and pericycle fibers are cross hatched. *A*, young ash stem, two hollow columns; *B*, stem of ivy, two hollow columns; *C*, stem of mint, I beams at corners; *D*, stem of smilax (monocotyledonous), hollow cylinder, interior a column reinforced by rods (the vascular bundles).

Hundreds of thousands of years before man discovered the advantages of the hollow column and I beam the bodies of plants were constructed upon these principles. Each cell of the supporting tissue is a hollow column. The supporting tissue of the cortex is a hollow column. The fibro-vascular bundles of the dicot stem are arranged in a hollow column. Each bundle is an I beam, with the xylem and the pericycle fibers forming the flanges and the phloem and cambium the web.

All of this illustrates that the cells, tissues and organs of plants and animals are usually such as best fit each for its ordinary environment; and to this adaptation the organism owes its continued life in its environment. The supporting system by which a plant meets the various stresses and strains of wind and other external forces, and holds up the leaves, flowers, and fruits in the air and sunlight, embodies excellent engineering principles. The supporting tissues of a root are fitted for a part which must not give away under considerable longitudinal pull; and its much-branched spreading arrangement anchors the whole plant to a large mass of heavy soil. The water-conducting cells of both stems and roots show the same sort of construction as do the structures which we employ to conduct water through our houses; they are long tubes with rigid walls. The epidermis of a root lies next to the plant's source of the life-giving water; and its cell walls are thin and their shape frequently such as will come in contact with a large surface of water. The epidermis of a young stem is the only thing that stands between the inner water-containing cells and the air into which the water might evaporate before reaching the leaves; and its cell walls are cutinized.

But this does not mean that the different kinds of cells were created by the plant's *need* for such cells in such positions.[5] Such a statement has no scientific meaning. When a building is put up, there is a human brain somewhere at work, foreseeing what materials, what types of structure, will be most useful. A plant, like Topsy, "just grows," and, as far as we know, cannot foresee what is best for it. And even if it could in some way anticipate

[5] Such a point of view may, however, be a useful guide. Thus, on the basis of need, plants which live immersed in the water and are supported by it should have little supporting tissue. This is the case. The stem which bears a heavy fruit like an apple is subjected to pulls, not compressions, and should have its supporting tissue in the center like the root and not near the epidermis as the main stem has. The supporting tissue of the fruit stem is, in fact, chiefly in the center.

its needs, it has, as far as we know, no nervous system, no muscles, no means at all of regulating its activities from a central place of control. Perhaps, as the plant grows, there *is* a builder or planner behind the scenes; but, since we have no *facts* indicating such a presence, such an idea takes us at once out of science and into the realm of the supernatural. Science is limited to those ideas which are based on things perceived (observable facts); it need not contradict ideas based on faith or anything else—but must refuse to be concerned with them. We must avoid saying, therefore, that supporting cells, for instance, are constructed as they are *because the plant needs rigidity*, or *in order to give it rigidity;* we must say, instead, that the plant is *rigid because* the supporting cells are what they are and where they are. What caused their formation we do not know. Having no facts, no *evidence*, which enable us to understand the cause of their appearance, we must frankly admit our ignorance—as far as scientific knowledge is concerned.

CHAPTER V

PHOTOSYNTHESIS, TRANSPIRATION, AND THE LEAF

ALL the materials which surround us can be more or less readily classed as *organic* or as *inorganic* substances. Stone, glass, water, copper, the minerals, salts and metals are examples of inorganic materials. Coal, petroleum, wood, sugar, starch, and meat are entirely or chiefly organic. The bodies of plants and animals, alive or dead, are (if we exclude the water) chiefly organic. About four-fifths of a plant is water and one-fifth is dry matter, and of the dry matter about 90 per cent is organic. In fact, the term organic was applied to these materials because it was believed that all such compounds came from organisms. This we have found to be incorrect, for the chemist can now make many organic substances in test tubes as satisfactorily as they are made in living bodies.

32. Dependence of Animals on Green Plants.—All organic compounds contain the element carbon, which is familiar in pure form as the diamond and as the "lead" (graphite) of a lead pencil. They contain also, combined with the carbon, one or more other elements such as hydrogen, oxygen, nitrogen, phosphorus, sulfur, iron, etc. Most organic compounds burn; that is, at certain temperatures they unite with the oxygen of the air, producing heat and light and certain gases, chief among which are carbon dioxide and water vapor. The most interesting fact, however, relating to organic substances is that among them are the *foods* upon which life depends. Animals and plants need (besides water, certain mineral salts, and vitamines) these organic materials, which are called foods, chiefly carbohydrates, fats, and proteins;[1] these substances are essential in the construction of plant and animal bodies and in furnishing them with active energy. Not only armies, but all men, "move on their stomachs" An essential part of our business of keeping alive is the taking into our bodies, usually three times each day, these materials which we call foods. The foods which animals eat come directly or indirectly from

[1] The characteristics of these groups of organic compounds are discussed in a later chapter.

plants. This is obviously true in the case of herbivorous animals, such as deer and cattle, and it is true also of the omnivorous or carnivorous animals, because the flesh they eat was formed from food of vegetable origin. There is much truth in Isaiah's statement that "all flesh is grass."[2]

There is a second important, though less obvious, way in which animals are dependent upon plants. It has been pointed out that, in burning, oxygen of the air unites with the organic material. In the process the oxygen and the organic material disappear as such, being transformed chiefly into water and carbon dioxide. In decay much the same thing happens. In using foods animals destroy part of them and transform them into carbon dioxide and water, and so we as well as other animals are continually using oxygen and forming carbon dioxide, which we exhale in breathing. If we fail to get this continuous supply of oxygen we suffocate. Burning, decay, and the life processes of animals continually destroy organic compounds, removing oxygen from the air and adding carbon dioxide to the air. Under such circumstances it is clear that, unless there is a place in the natural scheme of things where oxygen is formed and carbon dioxide removed, the oxygen content of the air should continuously decrease and the carbon dioxide content should increase. Analyses of the oxygen and carbon dioxide content of the air, however, have shown that little or no variation occurs in it from year to year or from decade to decade. The oxygen content remains near 21 per cent by volume and the carbon dioxide content near 0.03 per cent; which shows that there must be some way in which oxygen is added to and some way in which carbon dioxide is removed from the air. This is accomplished by the green plant; and it has been found, as the result of a long series of investigations from the time of Priestley, the discoverer of oxygen (1774), and of de Saussure (1804), to the present time, that the dependence of animals upon plants for food and the addition of oxygen to the atmosphere and removal of carbon dioxide from the atmosphere are all the results of one process, to which the name *photosynthesis* has been given. This process involves the formation in living cells which contain chlorophyll[3] of carbohydrates and oxygen from carbon dioxide and water by the action of light.

[2] Isaiah 40, 6.
[3] Chlorophyll is the green pigment contained in chloroplasts.

33. **Photosynthesis.**—If the leaf of a plant which has been exposed to sunlight is killed, decolorized, and treated with a solution of iodine, it becomes blue or blue-black in color. This reaction occurs only when starch or starch-like materials are treated with iodine, and we may conclude that the leaf contains starch. The plant has no outside source of starch; no test for starch can be secured in the soil in which it grows or in the air which surrounds it; the starch is made within the plant. In fact, the starch is made from sugar and the sugar from the gas, carbon dioxide, and from water. The sugar, glucose, is probably the first synthetic product of this reaction which can be demonstrated in the plant, but it is rapidly changed, in most plants, to starch. We, therefore, justifiably use the simple iodine test for starch to demonstrate the occurrence of photosynthesis in most plants.

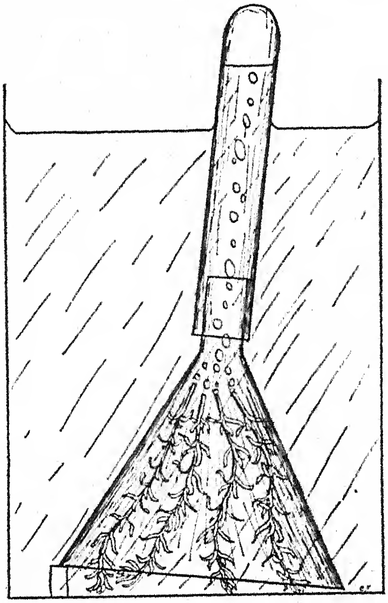


FIG. 44. An apparatus for collecting oxygen given off by *Elodea* in photo-synthesis.

By suitable experiments it may also be shown that oxygen appears within the leaf at the same time that sugar or starch does, but is given off into the air. A simple way of showing this is to expose a water plant like *Elodea* to strong light. The oxygen as

it is given off is easily visible, for in the water it forms small bubbles. If we wish we may collect these bubbles by placing the *Elodea* under an inverted funnel, using sufficient water to cover the funnel. If we now invert a test tube filled with water over the end of the funnel, the gas bubbles as they rise will displace the water and collect in the tube. If we place a thumb over the end of the test tube before we lift it from the water and then, as we remove our thumb, insert into the tube a glowing splinter, it will glow more brightly or burst into flame. This indicates the presence in the tube of more oxygen than there is in the air, since oxygen is the only gas which supports combustion.

These, then, are the products of photosynthesis: organic matter and oxygen. The first organic substance formed is glucose; from this are constructed all the other organic materials in the plant, fats and oils, cell walls, proteins, pigments, etc.

The raw materials from which the sugar and oxygen are formed are carbon dioxide and water. The first is absorbed by land plants from the air and the second secured from the soil. Water plants secure their carbon dioxide from that dissolved in the water in which they live. We may represent what occurs in photosynthesis in this way:

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2,$$ [4]

which means that six molecules of carbon dioxide and six molecules of water combine and form one molecule of glucose and six molecules of oxygen. Nothing like this happens in animals. They must find food ready-made and take it into their bodies; and no oxygen gas is given off from the animal's body.

34. Chloroplasts and Photosynthesis.—A process which furnishes us with the food we eat and the oxygen we breathe demands our close attention. Where in the plant does the transformation of carbon dioxide and water into carbohydrates occur? If we test a

[4] This is a *chemical equation* and represents a *chemical reaction* between the gas, carbon dioxide, and water. The molecule or ultimate particle of carbon dioxide is composed of one carbon atom and two oxygen atoms, the water molecule of one oxygen atom and two hydrogen atoms. In the reaction pictured above there are 6 carbon atoms, 18 oxygen atoms and 12 hydrogen atoms in the 6 molecules of carbon dioxide and 6 molecules of water. In some way these atoms are separated from one another and recombined to form the two new materials, glucose and oxygen. It is somewhat like the making of new buildings from the bricks of old ones. The same bricks are in the new structures, but they are arranged differently.

leaf which is partly green and partly white instead of one which is completely green, only that part of the leaf which is green will show the presence of starch. This suggests that the material which makes the leaf green, the chlorophyll, is connected with the presence of the starch. In fact, if we use a thin leaf like that

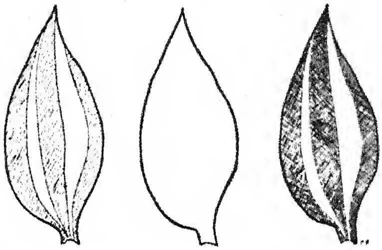


FIG. 45. The location of starch in a variegated leaf of wandering Jew. Left, the fresh leaf partly white and partly green; middle, after extracting the chlorophyll; right, after staining the decolorized leaf with iodine.

of *Elodea* and examine it microscopically after staining it with iodine, we can easily observe that the starch is within the chloroplasts and nowhere else in the cell. We might call the chloroplasts the photosynthetic factories or the machinery for photosynthesis.

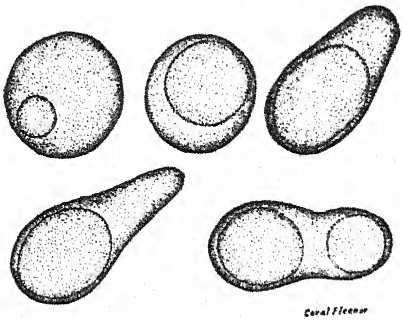


FIG. 46. A group of chloroplasts from an *Elodea* leaf. Each chloroplast contains one or two starch grains.

The chloroplasts of most land plants are differentiated portions of the cytoplasm shaped like biconvex lenses and containing four pigments: two green ones, chlorophyll alpha and chlorophyll beta; and two yellow ones, carotin and xanthophyll. None of these pigments is soluble in water and they are therefore never found

dissolved in the cell sap.[5] They are soluble in fats or oils and in fat solvents such as acetone, alcohol and petroleum ether. If we warm green leaves with alcohol we secure a green solution. This contains the chlorophylls, though in a form somewhat different from that in which they occur in the leaf. It contains also the yellow chloroplast pigments, as can be shown by adding some petroleum ether to the alcoholic extract. The petroleum ether and the alcohol form two layers, the former being green and the latter yellow, because the carotin and the xanthophyll are more soluble in the alcohol than in the petroleum ether while the reverse is true of the chlorophylls. We are certain that the green pigments are necessary for photosynthesis because leaves or plants which contain only the yellow ones cannot carry on the process. We are not sure, however, whether the yellow pigments are necessary.[6] The chlorophylls have a definite and known chemical composition. They are made of carbon, hydrogen, oxygen, magnesium, and nitrogen. When dissolved in alcohol they are green by transmitted light and red by reflected light. Such behavior is known as *fluorescence*. When chlorophyll is exposed to sunlight it is destroyed. This does not occur so rapidly if the chlorophyll is dry. So wet hay bleaches in the sun, and an alcoholic solution of chlorophyll retains its color in the dark but loses it in an hour or so in the sunlight, while hay which is quickly dried retains its green color, and chlorophyll dissolved in oil, which contains little water, does not decompose

[5] The colors of plants are due to plastid pigments, pigments dissolved in the cell sap or pigments deposited in the cell wall. Usually a green color is due to the chlorophylls in the chloroplasts. Yellow colors are due to carotin or xanthophyll in plastids (carrot, pumpkin) or to water-soluble pigments present in the cell sap. The latter are known as *xanthones* and *flavones* and in addition to being water soluble also become a darker yellow when made alkaline. The yellowish green color of the water in which greens are boiled is due to the xanthones or flavones and not to chlorophyll. Blue, purple, and most pink or red colors are due to water-soluble pigments dissolved in the cell sap. These pigments are called *anthocyans*. They are pink or red in acid solution and a purple or blue in more alkaline solutions. In the tomato and rose hip the red color is due to red plastids.

[6] The yellow pigments, carotin and xanthophyll, are responsible for the natural yellow color of cream and butter and the yolk of the hen's egg. The yellow pigments of the chloroplasts in the green feed are transferred unchanged to the fat of the animal or bird and some eventually appears in the fat of the cream or the fat of the egg yolk. Colorless cream or light-colored egg yolks show that the animals have had little feed containing carotin or xanthophyll. This may explain why carrots have been recommended for the complexion. The large quantity of carotin which they contain may color the body fat and produce a "creamy" complexion.

in the light very rapidly. This destructive effect of light on chlorophyll seems strange when we learn that light is also necessary for the development of chlorophyll in a plant. In the living plant the construction of chlorophyll, which is caused by light, exceeds the destruction of the chlorophyll which has been made.

35. **Light and Photosynthesis.**—If sunlight is passed through a prism a spectrum is formed, with the red light at one end and the blue and violet at the other. If the light is passed through a solution of chlorophyll and then through a prism, certain parts of

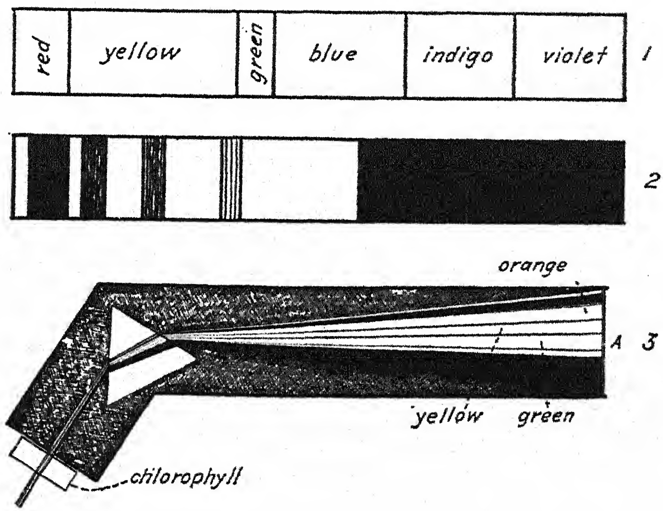


FIG. 47. *1*, normal spectrum; *2*, absorption spectrum of chlorophyll; *3*, diagram showing how absorption spectrum of chlorophyll is observed. Light passes through the chlorophyll solution, then through the glass prism in the tube, and the spectrum is observed at *A*. (*3* from Ganong, *The Living Plant*, Henry Holt & Co.)

the spectrum are missing, which shows that those kinds of light were absorbed by the chlorophyll. The chief colors absorbed are parts of the red, blue, and violet bands of the spectrum. The spectrum thus obtained is called an *absorption spectrum*. It is of interest because it shows just what kinds of light are absorbed by chlorophyll. And, since only those kinds of light which are absorbed by the chlorophyll are used in photosynthesis, we can thus determine the kinds of light which are instrumental in the manufacture of food.

Photosynthesis occurs only in the light. The formation of sugar from carbon dioxide and water is a sort of work, just as taking bricks from a number of small piles and putting them together to form a house is work; and work requires energy. The carbon dioxide and water will not build up of their own accord any more than bricks will. Light furnishes the necessary energy, and it is the only kind of energy which will perform this work in the green plant. Neither heat nor electricity nor any other form of energy will do this; they are not the right forms of energy. Trying to use them to manufacture carbohydrates would be like trying to build a wall by the energy of an electric light.

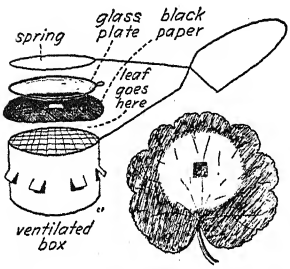


Fig. 48. Left, Ganong's light screen and aërated box for showing the necessity of light for photosynthesis. Right, a leaf stained with iodine after exposure in the screen to light.

In order that photosynthesis may take place we must have living chlorophyll-containing cells supplied with carbon dioxide and water and illuminated. The lack of any one of these prevents the occurrence of the process.

36. The Leaf.—Most of the photosynthesis in a land plant occurs in the leaves, because they contain the greatest part of the chlorophyll found in a plant, and because the structure of the leaves and their position on the stem enable them to secure carbon dioxide and to absorb light.

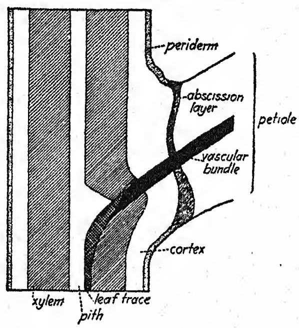


Fig. 49. A diagram to show the abscission layer at the leaf base in butternut, *Juglans cinerea.* (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

Most leaves consist of a stalk or *petiole* and a broad flat thin *blade*. In most kinds of plants changes in certain cells of the petiole finally cause the shedding of the leaf. These cells form usually a short zone, called the *abscission layer*, across the petiole near its base. At the time of leaf fall, the middle lamella of the cells in the abscission layer becomes chemically changed and breaks down or dissolves, often with adjacent layers of the cell wall. This

results in the separation of the cells of the abscission layer, leaving the vascular bundles as the sole support for the leaf. A breeze or a frost completes the break. The walls of the cells immediately below the abscission layer usually become waterproofed, protecting the inner tissues of the stem. When a plant is killed before the abscission layer has developed, the dead leaves remain attached. In some kinds of plants, for example the poplar, abscission of small branches also occurs.

The blade is rarely more than a millimeter thick. Running up through the petiole and traversing the blade in all directions are fibro-vascular bundles (*veins*). These are extensions of the fibro-vascular bundles of the stem and afford a means by which the water absorbed by the root reaches every part of the leaf. The breadth of the leaf causes it to intercept a great deal of light;

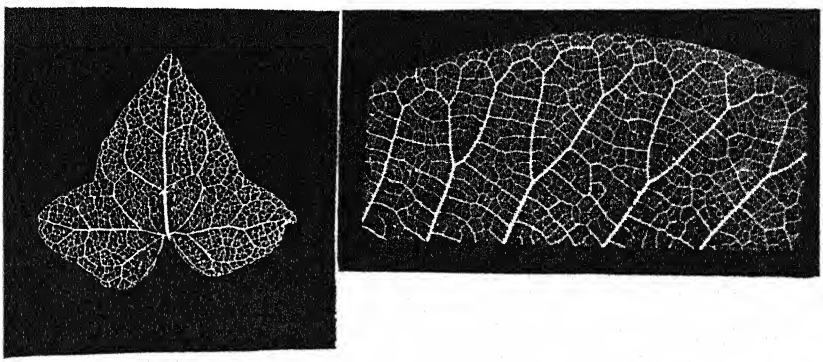


FIG. 50. The venation in leaves. (From Bower, *Botany of the Living Plant*, copyright 1919 by The Macmillan Company. Reprinted by permission.)

a single well-grown maple tree may have one-third of an acre of leaf surface. The thinness of the blade permits the light to penetrate all parts of it.

The surface of the leaf may be smooth or it may be covered with what must be for a small insect a jungle of single-celled or many-celled hairs. These grow from the outer layer of cells, the *epidermis*. The epidermis can be quite easily peeled off (especially from the lower side of the blade) and mounted under the microscope. Most of the epidermal cells contain no chlorophyll. They are shaped like tablets with wavy or irregular edges, and fit closely

together with no openings between them. There are also, here and there among these cells, some which contain chlorophyll and which are crescent shaped; these cells occur in pairs, with the

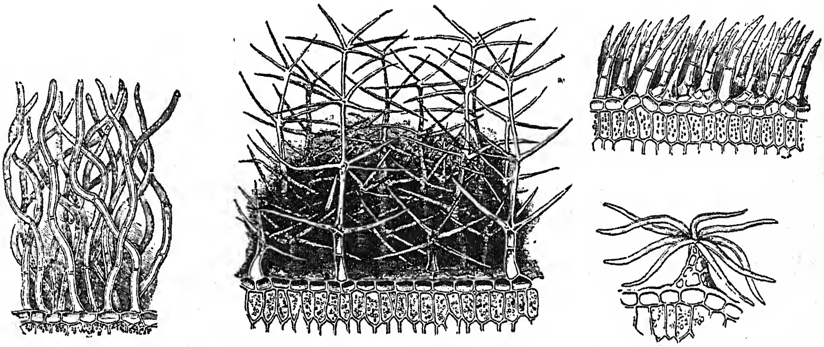


FIG. 51. Types of hairs found on leaves. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

ends of the crescents touching, so that there is a small elliptical opening between the two members of each pair. The opening is called a *stoma* (plural, *stomata*) and the two cells which surround it are called *guard cells*. A single stoma is very small. It is rarely more than 0.006 mm. wide and 0.018 mm. long, while the

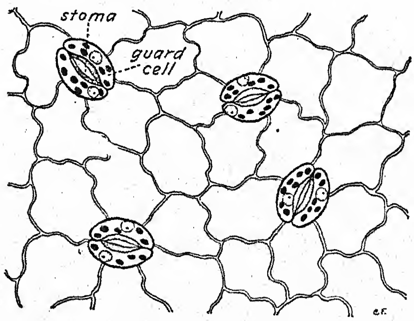


FIG. 52. A portion of the lower epidermis of a geranium leaf.

hole made by the finest sewing needle in a piece of paper would be about 0.600 mm. in diameter. Their number makes up for their small size, there being between 10,000 and 20,000 per square centimeter on the surface of the average leaf. When the guard cells become turgid the stomata are opened and when the guard

cells lose their turgidity they collapse somewhat and close the stomata. Light has great influence on the opening and closing of the stomata; at night and on cloudy days the stomata in most kinds of plants are closed; in bright light they are fully open.

A cross section of the leaf shows the upper epidermis on one side of the section and the lower epidermis on the other. Through one or both of these layers the stomata, surrounded by their guard cells, extend. The outer wall of the epidermal cells is partially impregnated and completely coated with cutin.[7] The cells between the two epidermal layers make up the *mesophyll* of the leaf. The cells of the mesophyll contain many chloroplasts. Those cells next to the upper epidermis are usually elongated and stand rather closely together. Because of their fancied resemblance to the palisades with which forts were surrounded in ancient times, they are called the *palisade layer* of the mesophyll. Below the palisade layer are chlorophyll-containing cells separated by large air spaces. These cells in a cross section of the leaf are approximately iso-diametric; in a longitudinal section they are of various irregular shapes, many having projections or arms which touch the neighboring cells. This portion of the leaf, because of the large air spaces, is called the *spongy mesophyll.* The air spaces in the spongy mesophyll are connected with one another and with the stomata. The walls of the mesophyll cells are not cutinized and, being in contact with the protoplasts, are always moist as long as the leaf is alive, just as a piece of filter paper laid on a piece of soaked gelatin is moist.

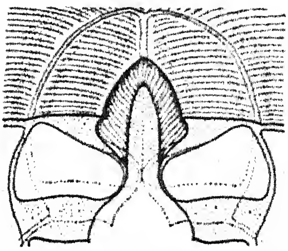


FIG. 53. A section through a stoma and guard cells. The dotted lines indicate the closed condition. (From Bower, *Botany of the Living Plant*, copyright 1919 by The Macmillan Company. Reprinted by permission.)

In the mesophyll, besides the palisade tissue and the spongy mesophyll, are the veins. A vein is a fibro-vascular bundle, which is connected with those of the stem. It consists of xylem and phloem, the cells of which resemble very closely the corresponding cells of the stem, but are considerably smaller. There is no cambium. Surrounding a vein is a sheath of large cells; in large

[7] The cutin forms a waterproof and, at ordinary pressures, a gasproof layer.

veins the walls of these cells are thick and form a rigid framework which helps to maintain the shape of the leaf; in small veins the sheath is composed of parenchyma. The largest veins often project on the lower side; they include many thick-walled cells and form strong ribs extending through the leaf.

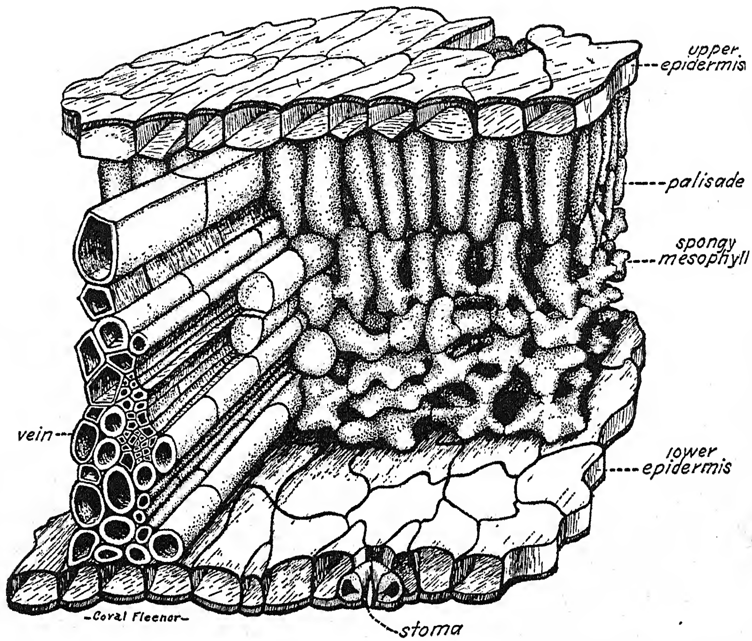


FIG. 54. A section through a portion of a leaf blade. To avoid confusion the chloroplasts in the mesophyll cells are not shown.

The typical leaf blade, then, consists of a thin but extended mesophyll made up of veins and of cells containing chloroplasts. It is covered by a cutinized epidermis which is pierced by small holes called stomata. The stomata are connected with an extensive system of air spaces ramifying throughout the leaf. These air spaces are surrounded by the moist walls of the cells of the mesophyll.

37. The Mechanics of Photosynthesis.—We can now describe how photosynthesis takes place. The carbon dioxide of the air diffuses through the stomata into the air spaces of the leaf. It dissolves in the water of the moist cell walls of the mesophyll

and then in solution (as carbonic acid) diffuses the short distance from the cell wall to the chloroplasts. There, under the influence

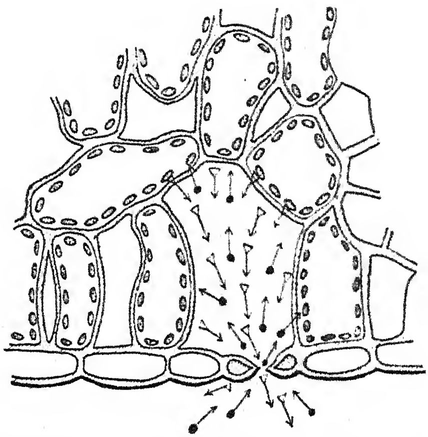


FIG. 55. A diagram of a section through the stoma and substomatal cavity of a leaf to show the direction of diffusion of gases in photosynthesis. The arrows with black balls represent carbon dioxide, those with triangles, oxygen.

of light and chlorophyll, the carbon dioxide and water combine to form sugar and oxygen. The sugar may be built up into starch in the chloroplast or, frequently after being moved to some other part of the plant, used to furnish energy, or changed into oil or fat or cellulose or into some other part of the plant's structure. The oxygen diffuses as dissolved oxygen to the cell wall, where it is given off as gaseous oxygen into the intercellular spaces, and later diffuses out through the stomata into the air.

38. The Amount of Photosynthesis.—The quantity of sugar made by a leaf varies with the kind of plant and the conditions under which it is carrying on photosynthesis. An average leaf makes a gram of glucose per square meter per hour. If we assume a ten hour day and a one hundred and fifty day summer season, then an average plant would make about fifteen hundred grams of glucose per square meter per season. A man requires the equivalent of seven hundred and fifty to one thousand grams of sugar per day to supply his food requirements. Each one of us needs therefore between 180 and 240 square meters of leaf surface working throughout the summer season to supply him with the food he requires during the year. About one hundred and fifty square

meters of leaf surface would furnish each of us with the oxygen he needs per year.

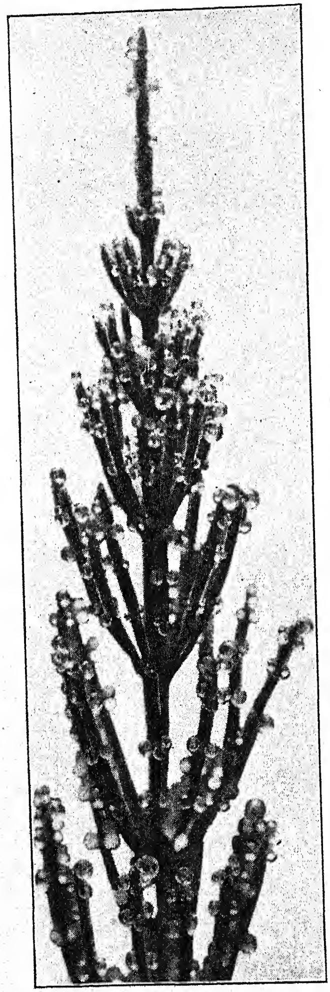


FIG. 56. Guttated water on the horsetail or scouring rush (*Equisetum*). (Courtesy of J. K. Wilson.)

The next time you see a leaf with the sun shining on it, think of it for a moment. It is more than something green; it is nature's greatest and most important factory, whose products are essential for the life not only of the plant but of almost all living things, including ourselves.

39. **Water Loss from Plants.**—The same structure in the leaf which allows the entrance of carbon dioxide and the escape of oxygen also permits water vapor to be lost from the leaf. Water constantly evaporates from the moist cell walls of the mesophyll into the intercellular spaces of the leaf and thence diffuses out through the stomata. We call the loss of water vapor from the plant *transpiration*.

Water occasionally escapes in liquid form also from plants. Certain leaves have small groups of cells on their margins which, under certain conditions, exude drops of water. Liquid water may be lost also from the ends of cut stems or branches. These processes, known as *guttation* and *bleeding* respectively, are relatively unimportant and are not included under the term transpiration, which refers only to loss of water as a gas.

The amount of transpiration under average conditions is surprisingly large. A sunflower may transpire 276 grams of water per square meter of leaf surface per hour. A single corn plant transpires about forty gallons of water in a growing season and a field of corn transpires enough water to cover with seven inches of

water the ground on which it grows. A single date palm transpires 100 to 190 gallons of water per day. This water is, of course, absorbed from the soil in which the plant grows.

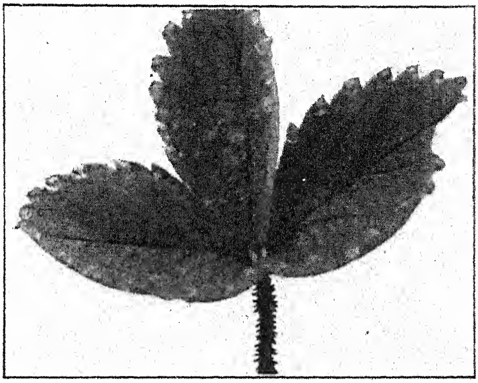


FIG. 57. Guttated water on a strawberry leaf. (Courtesy of J. K. Wilson.)

The transpiration of water by a living cell of a leaf increases its water-absorptive power by increasing the concentration of dissolved material in the cell sap and by partially drying the solid or semi-solid materials of the cell. Such a partially dried cell absorbs water from the water in the xylem vessels or from adjoining cells which in turn absorb water from that in the xylem vessels.

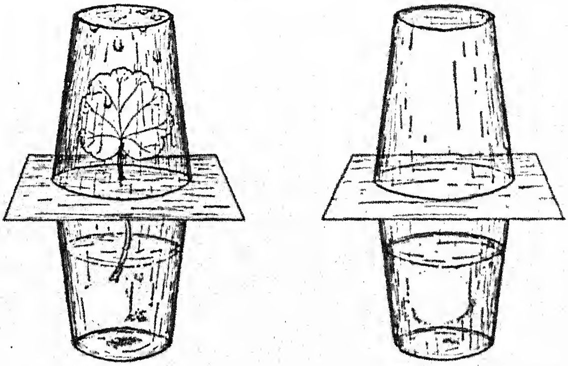


FIG. 58. A simple apparatus to demonstrate transpiration. Water vapor from the leaf in the left hand tumbler condenses on the glass. When no leaf is present no water appears in the upper tumbler.

Under the conditions in which water exists in the xylem vessels (thin columns supported on the sides) it has great tensile strength; it hangs together as the parts of a rope hang together. This is

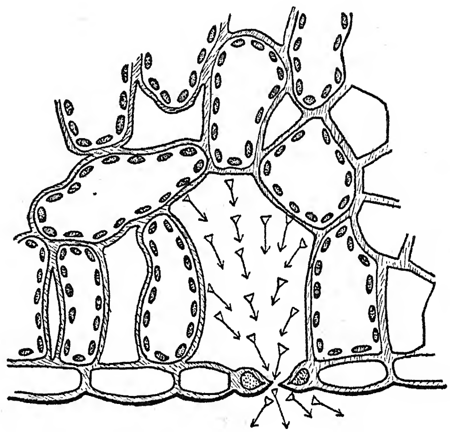


FIG. 59. A diagram to show how transpiration occurs through the stoma. The arrows represent water vapor.

because the water molecules cohere and the walls of the xylem vessels protect the column from rupture. The absorptive power of the leaf cells developed by transpiration is great enough to drag water up through the vessels of roots and stems to the tops of the highest trees, the water hanging together as the parts of a rope hang together when a pull is exerted at one end of it.

The rate of transpiration is not constant. It is most rapid under conditions of high temperature, wind, strong light, and low humidity—that combination of factors which most favors evaporation. At night, when the stomata are closed, it almost ceases.

If the leaves transpire more rapidly than the roots absorb water or the stem conducts it, then the water content of the plant will decrease. Such a decrease in water content first causes the growth of the plant to stop, and if it is continued the plant wilts. Efforts are made, therefore, by growers of plants to prevent such results, either by adding water to the soil or by reducing transpiration. The transpiration from a plant may be reduced by removing some of the leaves; this is frequently done during transplanting, when the absorptive system (root system) has been partly destroyed

in handling the plants. The same result is accomplished by plants by the shedding of leaves during a prolonged drought. Transpiration may also be reduced by shading the plant, which is accomplished by whitewashing greenhouses in the summer, by increasing the humidity of the air surrounding the plant, by lowering

FIG. 60. Determining the amount of transpiration from corn, *Zea Mays*. The plants are grown in moist soil in metal containers with tops sealed except for the opening where the corn plants are growing. Loss in weight of container and plant equals the amount of water lost in transpiration. (Courtesy of T. A. Kiesselbach and Nebraska Agricultural Experiment Station.)

the temperature, or by protecting the plant from the wind (as is done, for example, in orchards, by wind breaks).

40. **Effects of Transpiration.**—It has been suggested that various benefits to the plant result from transpiration. It has been stated that transpiration cools the plant just as evaporation from your skin cools you; but actual measurements have shown that the lowering of the temperature of a plant by transpiration is usually too slight to be of any importance. It has been stated that the absorption of water by the roots, which results from the loss of water in transpiration, helps the plant absorb the mineral salts from the soil solution. But we know that each substance, including water, diffuses by itself, and actual determinations have shown that plants with greater transpiration may not have greater ash content (and the ash content is a measure of the minerals absorbed). It has been stated that transpiration furnishes the force which

pulls water through the plant. This is true, but if there were no transpiration there would be no such need for water to be pulled through the plant. On the whole, we may describe transpiration as a necessary evil. It is necessary because a land plant could not be made in such a way that it would secure carbon dioxide and not transpire; surfaces which permit the entrance of carbon dioxide from the air necessarily permit also the evaporation of water into the air. It is an evil because excessive transpiration (transpiration which exceeds absorption) is harmful to the plant; it stops growth, causes wilting, interferes with photosynthesis, and finally causes death.

CHAPTER VI

Foods

THE foods which animals eat consist essentially of three classes of chemical compounds, the carbohydrates, the fats and the proteins. After being taken into the body, these foods [1] are used in two ways: they furnish the energy used in vital activities (such as movement and growth); and they are the materials from which the tissues of the body are built up. The bread and meat we eat today become skin and muscle tomorrow, or furnish the energy which enables us to move.

The plant uses the same foods as the animal. Carbohydrates, fats and proteins furnish the free energy used in the life processes of the plant, and supply the materials from which the parts of the plant body are constructed. An important difference between animals and chlorophyll-containing plants is the source of their food. The green plant makes its own foods from the inorganic materials, carbon dioxide and water.[2] Animals (and plants lacking chlorophyll) are unable to do this, and derive food ready-made from their surroundings.

41. **The Carbohydrates.**—The carbohydrates are composed of carbon, hydrogen and oxygen. The chief carbohydrates found in plants are the sugars, such as glucose, levulose, maltose and cane sugar, and the polysaccharides, such as starch, the pentosans and the celluloses. The sugars are all soluble in water and are sweet to the taste, cane sugar and levulose sweeter than glucose or maltose. Cane sugar crystallizes readily into the beautiful white crystals we see in the sugar bowl; the others do not crystallize; when they are dissolved in water it is impossible to distinguish between them

[1] The term *food* is used in a variety of ways. It is frequently used to refer to the mineral salts and nitrogen compounds which plants need. They are discussed on page 87 under the name of minerals. We have limited the term food to the organic materials which furnish energy or from which the major part of the dry matter of the body is made. While the mineral salts make a part of the body and are constructive materials, they form only a small part of the constructive substances, and are therefore not here called foods.

[2] Compounds of nitrogen, sulfur, phosphorus and other elements are also required for the construction of proteins.

by ordinary methods of examination. When heated with an alkaline solution of copper sulfate (Fehling's solution), glucose, levulose and maltose produce a red precipitate of copper oxide, while cane sugar does not. If, however, we add a small amount of an acid, such as hydrochloric acid, to the solution of cane sugar, and heat the mixture, we find that the solution thus formed acts upon Fehling's solution just as glucose, levulose and maltose do. The hydrochloric acid, in fact, causes the cane sugar to unite with water and to break up into levulose and glucose. In chemical symbols

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6.$$

We call this phenomenon *hydrolysis* because the cane sugar unites with water before or during its change; we refer to the action of the hydrochloric acid, which causes this change without becoming a part of the products formed, as *catalysis*. The acid itself is the *catalytic agent*.

Sugars are found in solution in the cell sap. In parts of some plants sugars accumulate in considerable amounts. Ripe bananas contain about 15 per cent sugar; apples, from 8 to 19 per cent; strawberries, 11 per cent; and sugar beets, about 15 per cent.

Starch is characterized by the fact that it unites with iodine and forms a blue compound. Starch is insoluble in water, though when we boil a small quantity in water it forms an opalescent false or colloidal solution. When boiled with an acid, however, starch, like cane sugar, unites with water and is changed to a different material. It is hydrolyzed to glucose; thus:

starch + water forms glucose,

or in chemical symbols:

$$(C_6H_{10}O_5)_n + nH_2O = nC_6H_{12}O_6.$$[3]

Starch occurs in the plant in the form of grains. Small starch grains are present in the chloroplasts, where they are the first visible product of photosynthesis. Large starch grains are found in storage cells, where they are formed from sugar by and within the leucoplasts.

[3] The "n" in this equation means that we do not know just how many molecules of glucose are formed from one molecule of starch. It is probably near 36.

The shape, size and structure of starch grains is more or less peculiar to the kind of plant in which they are formed. The starch grains of a potato average 0.09 mm. in diameter. Each

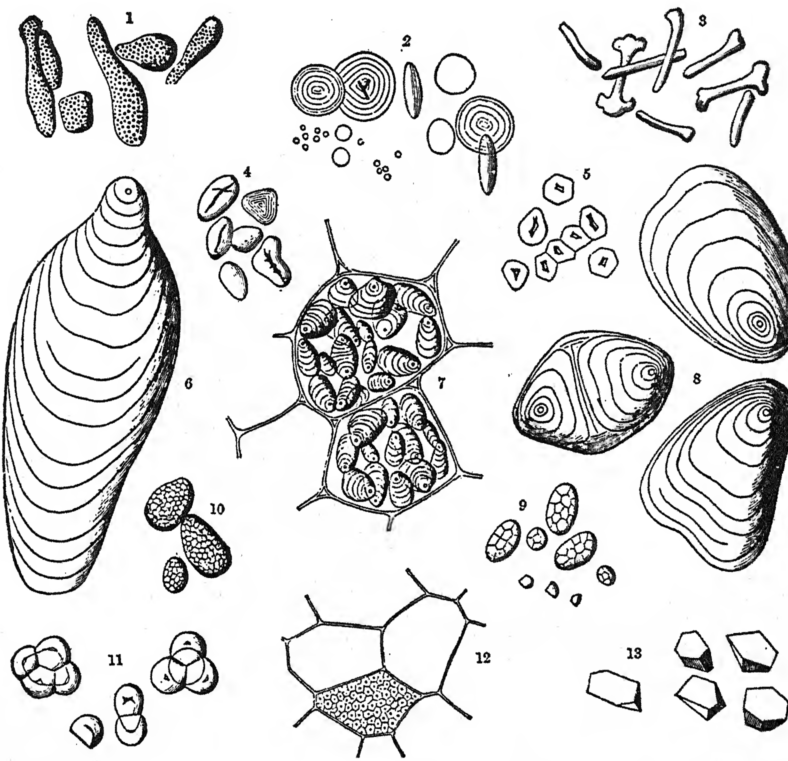


FIG. 61. Various forms of starch grains. *1*, from the seeds of the corn cockel (*Agrostemma Githago*); *2*, from a grain of wheat; *3*, from spurge; *4*, from a bean seed; *5*, from a grain of corn (*Zea*); *6*, from the rootstock of *Canna; 7*, from a potato tuber (grains enclosed in cells); *8*, from a potato tuber (grains isolated and very highly magnified); *9*, from a grain of oats; *10*, from the seed of *Lolium temulentum; 11*, from the corm of meadow saffron (*Colchicum autumnale*); *12*, from a grain of rice; *13*, from a grain of millet. All highly magnified. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

looks superficially like an oyster shell, with its curved lines extending from a point near one edge. The starch grains, however, are not flat. The lines one sees are caused by layers of starch, each of which is more or less egg-shaped and completely encloses the one

next within it.[4] Stratification is visible because of the varying densities of successive layers; dense layers which appear clear by transmitted light alternate with less dense layers which appear darker. The starch grains of the potato may be simple, half compound, or compound. Half compound grains are made up of two or more individual grains surrounded and held together by a zone of peripheral layers. The compound grains consist of an aggregate of individual grains with no common enveloping layers. Starch grains of other kinds of plants may differ from those of the potato in size, in shape, in being concentric, in containing fissures, or in being all compound.

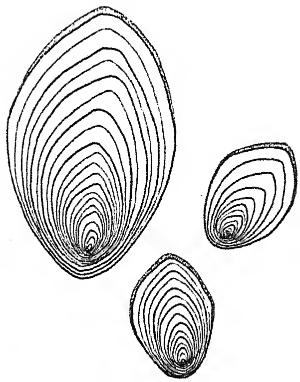


FIG. 62. Single grains of potato starch; a leucoplast may be seen as a faintly visible envelope around each grain.

In storage cells starch grains are formed within the leucoplasts. If the grain is uniformly surrounded by the leucoplast during its formation it increases in size uniformly, and is symmetrical about the hilum. If, however, the formation of the starch grain begins nearer one edge of the leucoplast than the other, the grain will grow more rapidly on the side next the main body of the leucoplast, and thus be eccentric.

The amount of starch present in storage organs is often very high. About 25 per cent of the weight of the white potato tuber, and as much as 70 per cent of the wheat grain, is starch.

Cellulose stains brown with iodine. It is not soluble in water, but when treated with strong sulfuric acid or heated with more dilute acid it is changed first to a starch-like material which stains blue with iodine, and finally to the sugar glucose. We can represent the action of this catalytic agent, the acid, in this way:

cellulose + water forms glucose,

or

$$(C_6H_{10}O_5)_x + xH_2O = xC_6H_{12}O_6.$$

Cellulose makes up the chief constituent of the cell walls of plants.

[4] The layers are called *strata* (singular, *stratum*), and the inmost bit of starch, about which the layers are formed, is called the *hilum* (plural, *hila*).

It is usually present not as pure cellulose but intermixed with various other materials or variously modified. Cotton is almost

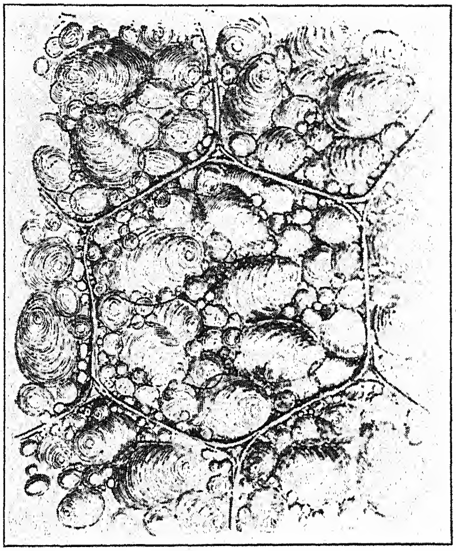


Fig. 63. Starch grains in cells from the tuber of potato, *Solanum tuberosum*. (From Figuier, *The Vegetable World*, Hachette et Cie.)

pure cellulose and such things as paper, wood and straw are largely cellulose.

42. **The Fats.**—The fats also are composed of carbon, hydrogen, and oxygen, but the proportion of carbon is higher than in the carbohydrates. They are characterized by the fact that they make a persistent translucent spot on paper, by the fact that they are blackened by osmic acid, and by the fact that they are stained strongly by such dyes as Sudan III, while carbohydrates and the proteins are not. The fats are not soluble in water, but if they are heated with a strong alkali, the alkali, acting as a catalytic agent, causes them to hydrolyze into water-soluble products, thus: fat plus water forms glycerine and a fatty acid. Fats occur in the walls of some cells, but more often as drops in the vacuoles or protoplasm. The quantity of fat in parts of some plants is very high. The kernel of the peanut contains from 45 to 50 per cent, the soybean about 8 per cent, the meat of the cocoanut about 60 per cent, and the castor bean about 50 per cent oil or fat. In

cooking, soap-making and the like, fats and oils from plants have largely replaced the more expensive ones derived from animals.

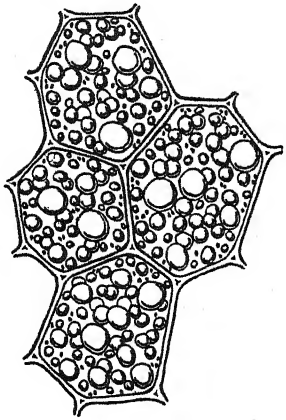


FIG. 64. Cells from the endosperm ("meat") of the coconut. The large globules are oil, the small granules protein.

43. The Proteins.—The proteins differ decidedly from the fats and carbohydrates in containing not only carbon, hydrogen, and oxygen but also nitrogen and often sulfur, phosphorus, and other elements. They are characterized by the colors they produce with certain reagents. Many proteins become yellow when treated with nitric acid. This yellow color will deepen to orange if sufficient ammonia is added. They produce a pink color if heated with mercury dissolved in nitric acid (Millon's reagent). Neither fats nor carbohydrates do these things. The proteins are not soluble in water, but if heated with acid or alkali they too are changed to water-soluble materials, such as amino acids and ammonia. The proteins are the chief constituents of the protoplasm, and they are present also as fine granules in the vacuolar sap, and frequently as larger granules in the cytoplasm.

The proteins, fats, starch, and cellulose have one characteristic

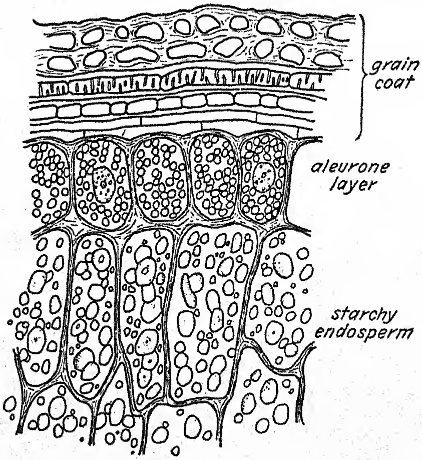


FIG. 65. The aleurone layer in wheat. Part of a section of a wheat grain showing aleurone layer with cells filled with granules of protein.

in common: they are all insoluble in water. But by the use of high temperatures and strong acids or alkalies it is possible to change them into water-soluble substances.

44. **Digestion.**—Such a change from insoluble to soluble condition evidently occurs in living organisms, else starch or fat or protein could never be used in any cell save that in which it happened to be made. This change of an insoluble to a soluble substance, which we call *digestion*, must precede the transfer of starch, cellulose,[5] fat or protein from one part of the plant to another. In fact, it can be observed. A chemical analysis of ungerminated and germinated wheat grains shows that the starch content is

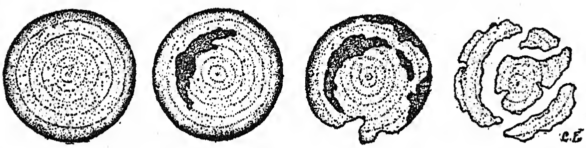


FIG. 66. Stages in the digestion by diastase of starch grains of wheat.

high in the former and the sugar content low, while in the germinating wheat grains the sugar content becomes higher and the starch content lower. If we examine the starch grains from the two kinds of wheat grains, we can actually see that they are destroyed during germination when the sugar content rises. In the ungerminated wheat grains they are smooth and regular in appearance, in the germinating wheat grains they are corroded on the surface or fragmented. They are being converted into maltose sugar, which dissolves.

45. **Enzymes.**—How is digestion accomplished by living protoplasm? We can change starch to sugar by the use of strong acids and heat (the temperature of boiling water), but such acidity and high temperature would be fatal to living protoplasm. The change of starch to sugar which occurs in the germinating wheat grain occurs at ordinary temperatures and at very slightly acid or alkaline reactions. Is this power of changing insoluble things to soluble things at ordinary temperatures and ordinary reactions a peculiarity of living things and one of the characteristics which distinguishes them from non-living things? It was once considered so. However, if we make a water extract of germinating wheat grains and

[5] Many animals, including man, cannot digest cellulose. It cannot, therefore, serve as a food for them.

add sufficient alcohol to the extract, a whitish precipitate is secured which, when resuspended in water and added to a starch suspension, changes starch to sugar at ordinary temperatures and reactions. This precipitate is not alive, for poisons, such as strong alcohol and toluene, which kill living things, do not destroy its ability to digest starch. We conclude therefore that some material, which is not alive, and which can change starch to sugar at ordinary reactions and temperatures, is contained in the precipitate. It is the presence of this material in the living wheat grain which enables it to digest starch. We call this substance *diastase* or *amylase*. In much the same way we can show that there are in living protoplasm other substances similar in nature to diastase, which enable it to digest fats and proteins and cellulose; which cause, in fact, the rapid occurrence in plants and animals of a great variety of chemical transformations which would otherwise go on only very slowly at the temperatures and reactions found in living things. Each of these has been named. There are the proteases, for example pepsin and trypsin, which digest proteins to amino acids, the lipases, which hydrolyze fats to glycerine and fatty acids, the oxidases, which facilitate oxidations, zymase, which changes glucose to alcohol and carbon dioxide, and many others. The general name given to this class of substances is *enzymes*.

We know the chemical nature of only one enzyme. Urease, which transforms the compound urea into ammonium carbonate, has been found to be a protein of the globulin type. No one has yet succeeded in freeing any other enzyme from accompanying materials and determining its chemical composition. We know that the enzymes are not alive, that they are with very few exceptions destroyed by a temperature of 100° C., that there is a considerable number of different enzymes, that a single cell may form many enzymes and that they act as catalysts. We assume that they are organic in chemical nature and define them as organic catalytic agents produced by living protoplasm.

46. Translocation of Foods.—Once digestion has occurred, the soluble food material diffuses from cell to cell. The path which digested food follows, in moving from the leaves to the root or from the root to the leaves, is through the phloem of the fibrovascular bundles. Cutting the phloem or interrupting it in any way will prevent the movement of food material up or down the stem. The movement of food we call *translocation*.

When we cut away a ring of bark on a tree trunk the tree dies, because the food made in the leaves cannot reach the roots, and they starve. A tree bound tightly by a wire often shows an enlargement above the wire. The normal increase in diameter of the trunk tightens the wire and interferes somewhat with translocation from the leaves. The accumulation of food material above the wire causes more rapid growth there.

47. **Origin of Starch in Potato Tuber.**—We can illustrate the processes we have been describing by considering the origin of the starch which we find in a potato tuber. In the chloroplasts of the leaves of the potato plant sugar is formed from the carbon dioxide of the air and water secured from the soil. The sugar is built up into starch in the chloroplasts. This starch is digested by the enzyme diastase to sugar. The sugar which is not at once used diffuses from cell to cell to the phloem of the veins of the leaf. It moves down the phloem of the leaf veins and through that of the bundles of the petiole into the stem and down the phloem of the stem into the underground stems where the tuber is developing. The sugar arriving in the young tuber is built up again into starch in the leucoplasts. When the potato is planted and a bud begins to grow, part of the food which the young bud uses is furnished by the starch which is in the tuber. Again the starch grain is digested and the soluble sugar diffuses from the cell in which the starch grain was located to the growing bud, where it is used to build new tissues or to furnish energy.

48. **Origin of Other Foods.**—The description of the formation of starch in a potato tuber shows how one food (the carbohydrate, starch) originates. The other foods also are constructed from the sugar formed by photosynthesis. For example, the oil in a peanut is made in the cells of the peanut seed by the transformation of sugar translocated from the leaves of the peanut plant through the phloem. Proteins, however, are not made from sugar alone, for they contain nitrogen and sulfur, and sometimes phosphorus and other elements, in addition to the carbon, hydrogen, and oxygen which alone are present in sugar. It is evident that for the construction of protein green plants need some form of nitrogen, of sulfur and of phosphorus in addition to the carbon dioxide and water from which sugars are made. The phosphorus and sulfur in the form of salts, for example phosphates and sulfates, are absorbed through the roots from the soil solution. Most kinds of

green plants absorb the nitrogen as ammonium salts or nitrates in the same way. These materials unite in the plant with sugar and are built up into protein.

Most kinds of plants are quite unable to use the huge quantity of gaseous nitrogen which makes up about four-fifths of the air.

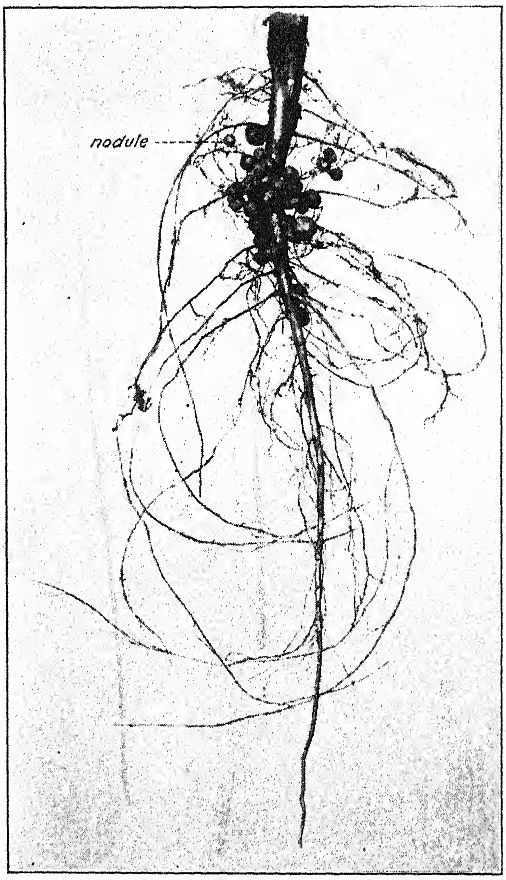


Fig. 67. Nodules on the root of soy bean (*Soja*). (Courtesy of W. A. Albrecht.)

This is unfortunate, as ammonia and nitrates are frequently scantily present in the soil and are expensive to buy. Certain microscopic plants belonging to the group known as the bacteria can use gaseous nitrogen, and one kind lives in the tissues of the roots of leguminous plants, for example alfalfa, the clovers, beans and peas. They

produce swellings, called nodules, on the roots of these plants, but not on other common kinds of plants such as wheat or corn. The bacteria in the nodules change the gaseous nitrogen into some

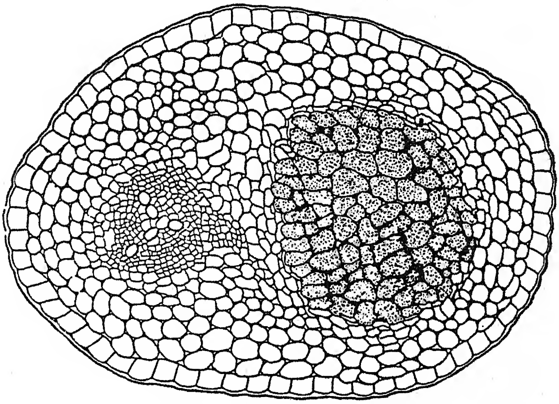


FIG. 68. Cross section of root and young nodule of red clover (*Trifolium pratense*). The shaded cells contain the bacteria. (From Knudson, Cornell Agricultural Experiment Station Extension Bulletin 2.)

combined form which the plant on which the nodule is can utilize. In this roundabout way the legumes can secure their nitrogen from the air, while wheat and corn and grass cannot. When the legume dies its body decays and the nitrogen contained in it is left in the soil as ammonia or nitrates, which other plants may use. Legumes with their nodules which contain the nitrogen-fixing bacteria are important therefore in any crop rotation because of the nitrogen which they remove from the air and leave with their bodies in the soil.

49. Food Relations of Plants and Animals.—Animals and chlorophyll-containing plants differ in at least three ways in their relation to food. Not only does the green plant make from carbon dioxide and water the carbon-containing foods but it also constructs proteins from carbon dioxide, water and inorganic nitrogen (nitrogen not contained in carbon compounds). An animal can do neither of these things. If we were to eat sugar and ammonium salts or nitrates but no protein, we would starve because of our inability to construct the proteins, which are essential parts of the protoplasm and other materials of the body. Animals must be supplied from without with organic nitrogen compounds (for example proteins)

and carbon in such form as it is found in the carbohydrates, fats or proteins. Furthermore animals are apparently unable to make the accessory foods, the vitamines. These too must be derived directly or indirectly from plants.

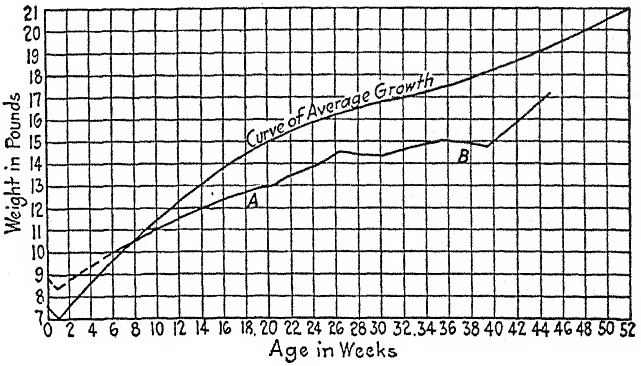


FIG. 69. Vitamines and growth. Weight curve of an infant showing the need of vitamine C. At *A* the infant was weaned and placed on a diet deficient in vitamine C. At *B* the administration of orange juice was begun. (From Mitchell, *General Physiology*, McGraw Hill Book Co., Inc., New York, N. Y.)

50. Storage of Foods.—We have already noted that part of the food manufactured in the leaves is stored somewhere in the plant. While small quantities of food may occur in any part of a plant, considerable accumulations may be found in particular storage tissues. Stored sugars are found in the pith of upright stems, such as those of the sugar cane and sorghum; in roots, such as that of the beet; in some bulbs, for example the onion; and in fruits, such as apples and grapes. Starch is found in various underground organs, for example the potato tuber (an underground stem), the sweet potato root; in some upright stems, such as that of the sago palm; and in many seeds, such as those of wheat and corn. In some plants the food is stored as a form of cellulose in thickened cell walls, as in the date seed, and in the seed of the vegetable ivory palm, which is used for making buttons (see Fig. 9). Fats or oils are common in seeds, as in those of the cotton, the cocoanut, peanut, castor bean, and soybean, and in some fruits, such as the olive. Food is stored as protein notably in the seeds of pea and bean. Plant parts frequently contain more than one kind of stored food; an example is a grain of corn, which may

contain starch, protein, and oil. The storage organs of plants have more than a scientific interest for us, since it is on them that man depends for much of his sustenance. The mere capacity of his stomach would make it difficult for a man to secure sufficient food if plants had no storage organs in which food is accumulated and he was forced to depend upon parts, for example leaves, in which the stored food is small in quantity. This is illustrated by the stomach capacity of such animals as the cow, which live on leaves of grasses and other plants.

51. Mineral Requirements of Green Plants.—Besides carbon dioxide, water and suitable forms of nitrogen, sulfur and phosphorus,

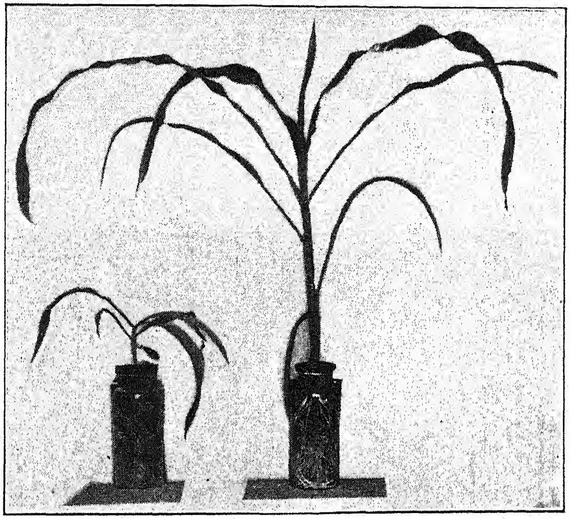


FIG. 70. Left, corn grown in water solution containing all the essential elements except iron; right, in a water solution containing all the essential elements including iron. (Courtesy of Carl Deuber.)

a green plant must be supplied with salts of iron, potassium, calcium, magnesium, and possibly very small quantities of salts of manganese, boron and zinc. The iron, potassium, calcium, magnesium, manganese, boron and zinc, together with the phosphorus and sulfur, are called the essential mineral elements. None of these is needed in very large amounts, yet each is essential for the continued life and growth of the plant. The total amount of all of these elements is rarely more than 1 or 2 per cent of the

fresh weight of the plant. The amount of iron in a corn plant may be no more than in an ordinary needle, yet the absence of that iron will interfere with the normal growth of the plant. All of the mineral elements are secured by the plant from the soil solution. When placed with its roots in the following solution and exposed to the sunlight and air, a green plant is supplied with all of the raw materials needed for the construction of its food and the continuance of its life.

Potassium acid phosphate (KH_2PO_4)	0.9 gm.
Calcium nitrate ($Ca(NO_3)_2$)	0.55 gm.
Magnesium sulfate ($MgSO_4$)	1.1 gm.
Iron sulfate ($FeSO_4$)	0.01 gm.
Sodium borate, zinc sulfate and manganese chloride [6]	trace
Water	1,000 cc.

[6] Boron, zinc and manganese are present as contaminations in most chemicals and need not usually be added to the solution.

CHAPTER VII

The Relations of Living Things to Energy

Any agent which is able to do work is said to possess energy, and the amount of energy an agent possesses is equal to the total work which it can do. Thus the spring of a watch, when wound, is in a condition to do a definite amount of work. What energy is we do not know, any more than we know what electricity is. We know energy only through its manifestations, the work it is able to accomplish.

In grasping the idea of energy it is important to distinguish between the agent which merely transforms energy and the agent which actually has within itself the ability to do a certain amount of work. Thus the steam engine merely transforms the energy of the fuel, coal, wood or petroleum, into mechanical work, and a water wheel merely transforms the energy of an elevated store of water into mechanical work, whereas a coiled watch spring has a store of energy within itself.

Whenever an agent gives up the energy which it has in store, it undergoes change. The coal which supplies the energy to a steam engine undergoes chemical change, uniting with the oxygen of the air, and changing chiefly into the gas carbon dioxide and into water vapor; the watch spring changes shape as it gives off its energy; the water which moves the water wheel changes position.

Not only does an agent undergo a change when it gives up energy, but it undergoes a change also when it receives and stores energy. A watch spring changes shape as it is coiled, water pumped into an overhead tower changes position.

52. Forms of Energy.—We have no means of knowing how many forms of energy there are; there may be an infinite number or only one. But for convenience we can group the manifestations under several heads, such as kinetic and potential energy. Kinetic energy is the energy of motion which a moving object has, potential energy is energy of position, as illustrated by the energy of a coiled spring or the water in an overhead tank. We can also group the manifestations of energy as heat energy, electrical energy, radiant

or light energy, chemical energy (for instance, that possessed by a lump of coal), and so on.

There is another convenient way of grouping the forms of energy; we may speak of stored energy and of active energy. A storage battery or a dry cell has stored energy—a lump of coal or a pound of sugar has stored energy—a coiled watch spring has stored energy—a tank of water overhanging a water wheel has stored energy. When the storage battery or dry cell is connected by wires the stored electrical energy becomes active—when the coal or sugar is burned the stored energy becomes active—when the watch spring uncoils the stored energy is set free—when a vacuum bottle is opened or the spigot on the water tank is opened the stored energy is set free.

One form of energy may be transformed into another. Light energy may be absorbed by a black cloth and transformed into heat energy. Electrical energy, in passing through a resistance wire, may be transformed into heat energy; or it may be transformed by a dynamo into kinetic energy or energy of motion. The chemical energy of a lump of coal may be transformed, by burning, into heat energy, the heat energy may be changed by means of an engine into energy of motion, the energy of motion may be transformed by a generator into electrical energy, and the electrical energy may by suitable apparatus be transformed into heat, light, or energy of motion. All forms of energy may be transformed into heat energy. Heat energy may be measured by the calorie, which is the amount of heat required to raise the temperature of one gram of water one degree Centigrade.

53. **Conservation of Energy.**—As a result of countless experiments in the chemical and physical world it has been found that when a quantity of one form of energy disappears an exactly equivalent quantity appears of some other form or forms.[1] The heat which is generated when coal is burned under the boiler of a steam engine can be accounted for in the heat which is dissipated into space, in the kinetic energy of the engine, etc. The results of these experiments have been combined into the statement that energy can neither be created nor destroyed; the total energy of

[1] The possibility of the transformation of matter into energy and energy into matter has been indicated by the most recent experimental work. The relation of this to the laws of conservation of energy and mass is not clear; but, so far as living organisms are concerned, such transformations, if they occur, are quantitatively insignificant.

the universe is constant. This statement is called the law of the Conservation of Energy. It is important to note that, while we have never succeeded in creating nor in destroying energy, we can dissipate it, that is, change it from an *available* to an *unavailable* form. A lump of coal or a quart of petroleum represents a readily available store of energy. If the coal or petroleum is burned in the open air the heat formed is dissipated, and we have no means of collecting it again. The available energy of the coal or petroleum has become unavailable.

Every living thing requires a continuous supply of energy. The energy is used in movement, in the construction of body parts, in the production of heat (especially by warm-blooded animals), of light (by the firefly), of electricity (by the electric eel). From where does this energy come? Does the law of the Conservation of Energy express the facts in living as well as in non-living things; or are living things exceptional in being capable of creating or destroying energy?

As far as our experimental methods permit us to judge, the law holds for living things. The energy involved in the development of heat, light, electrical phenomena, in movement and in the construction of the complex chemical compounds which make up the body of the organism is not created but represents a change in the form of energy already present. The energy already present in the organisms is the energy stored in foods. In the destruction of foods by the organism the stored energy is transformed into some active form, such as heat or light or electricity, or it is stored in other organic compounds which are made. The process by which the energy stored in chemical compounds is set free in living organisms is called *respiration*. This process is distinguished from digestion by the fact that in the latter process the food is merely transformed to another sort of food, very little of the energy being released.

54. **Products of Burning.**—You will naturally inquire how we know that anything like this occurs. Let us learn first what happens when the stored energy is set free from such compounds as wood or coal or sugar. The simplest way of doing this is by burning. When coal or wood is burned, heat and light are developed. At the same time the coal is transformed into carbon dioxide and water vapor, both of which go off into the air, the mineral matter remaining as the ash. Likewise when sugar is

burned it combines with oxygen, with the result that carbon dioxide and water vapor are formed and heat and light are developed. In burning, 180 grams of glucose combine with 192 grams of oxygen and form 264 grams of carbon dioxide, 108 grams of water and 373,000 calories of heat. Notice that the weight of the materials which combine equals that of those formed. No matter is lost; though its form or character has been changed it is indestructible. The same is true of the energy. In this reaction the chemical energy stored in the sugar is changed to heat energy. We may represent this process in chemical terms in this way:

$$\underset{\text{stored in the glucose}}{373{,}000 \text{ calories}} \quad \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} = \underset{\substack{\text{carbon}\\\text{dioxide}}}{6CO_2} + \underset{\text{water}}{6H_2O} \quad \underset{\text{heat}}{373{,}000 \text{ calories}}$$

55. Aërobic Respiration.—An analogous process takes place in living things. Oxygen is absorbed in burning and living things absorb oxygen. Suppose we fill a bottle one-third full of germinating seeds and stopper it tightly. If we remove the stopper after a few hours and carefully lower into the bottle a burning splinter, the flame goes out. If we do the same thing with a bottle

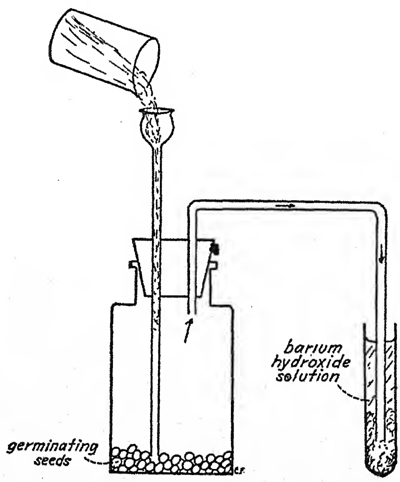


FIG. 71. A simple apparatus to demonstrate the production of carbon dioxide by plants.

which contained no peas, the splinter continues to burn for a minute or so. Gaseous oxygen must be present for burning. We must

conclude that in the bottle containing the peas the oxygen has disappeared, since all other conditions for the splinter's burning are present. The same thing would occur if we were to place living roots or leaves [2] or a frog or a man in a closed space. The oxygen would disappear.

As the oxygen is absorbed by the living tissue, carbon dioxide gas is formed. This also can be demonstrated by experiment. We enclose some living tissue, such as germinating seeds, in a bottle. In the stopper of the bottle we place a thistle tube and a piece of bent glass tubing. After a few hours we pour water into the thistle tube, so forcing the gas in the bottle out through the bent piece of glass tubing. The gas is conducted by the glass tube into a solution of barium hydroxide. This material forms a white precipitate [3] with carbon dioxide. The gas from a bottle which contains germinating seeds forms a heavy white precipitate in the barium hydroxide solution, while the gas from a bottle which contains no peas produces very little precipitate. Evidently the germinating peas formed carbon dioxide.

When organic material, such as wood or sugar, is burned, it disappears, being transformed by burning into carbon dioxide and water vapor. It disappears in living things also, and their dry weight becomes smaller and smaller, unless they secure a fresh supply of food.

Living organisms also produce heat. This is obviously true in warm-blooded animals which maintain the temperature of the body at a constant point. It is true also of plants and other living things whose body temperature is close to that of the air or other medium which surrounds them. The development of heat by such organisms can be demonstrated by placing them in a Dewar flask or vacuum bottle, which prevents the heat which they may develop from being dissipated into the air. The temperature in a vacuum bottle containing living plant tissue may become 20° or 30° C. higher than that of the outside air.

The formation of water in plants is difficult to demonstrate,

[2] It would be necessary to keep the leaves in a darkened bottle to show that they absorb oxygen. Why?

[3] The reaction which takes place is

Barium hydroxide +	carbon dioxide =	barium carbonate +	water
$Ba(OH)_2$	CO_2	$BaCO_3$	H_2O

because of their large and variable water content. With suitable precautions, however, it can be demonstrated.

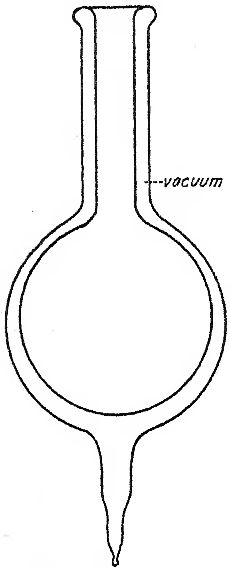


FIG. 72. A diagram of a Dewar flask (vacuum bottle).

By experiments such as those described above we can show that in living things a process occurs very similar to that which occurs in burning. It does not proceed in the living organism nearly so rapidly as when substances burn. For this reason respiration is sometimes referred to as slow combustion or slow oxidation. Enzymes are responsible for the combustion or oxidation occurring at low temperatures.[4]

56. Anaërobic Respiration.—The type of respiration which we have described above involves the absorption of oxygen, which usually comes from the air. For that reason it is referred to as *aërobic respiration*. The energy stored in chemical compounds may, however, be at least partially released without any free or gaseous oxygen being involved in the process. Glucose may be changed to alcohol and carbon dioxide, according to the following equation:

$$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2.$$

This means that from 180 grams of glucose 92 grams of alcohol and 88 grams of carbon dioxide may be made. No gaseous oxygen is involved here. The glucose molecule is broken into alcohol and carbon dioxide. In this change some of the stored energy of the glucose is set free, but not all of it. Much remains in the alcohol. In fact, while 373,000 calories are set free when 180 gms. of glucose are burned, only about 25,000 are developed when the same quantity is changed to alcohol and carbon dioxide.[5]

Organic compounds may undergo similar changes in the bodies of plants and animals. A test tube may be filled with mercury

[4] The food material might be compared to the coal supplied an engine, the protoplasm and enzymes produced by it to the engine.

[5] This means that 92 gms. of alcohol contain the difference between 373,000 and 25,000 or about 348,000 and that if we were to burn 92 gms. of alcohol under a pan containing 10 liters of water, and if all of the heat produced were retained by the water, it would raise the temperature of that water 34.8° C.

and inverted in a pan of mercury, and some germinating seeds slipped into the tube so that they rise up to its closed end. The tube, being full of mercury, contains no oxygen, yet after a day or two the seeds form a gas, and the gas forces the mercury down in the tube. This gas we can prove to be carbon dioxide. This shows us that carbon dioxide may be produced by living tissue without any gaseous oxygen being used. The development of alcohol in seeds which lack free oxygen has also been demonstrated. Other substances than alcohol may be formed; for instance, organic acids. We call this kind of respiration *anaërobic* because it goes on in the absence of gaseous oxygen. Most kinds of plants and animals cannot live long if they are limited to anaërobic respiration, probably because the amount of active energy they receive is too small and because the alcohol or other material formed

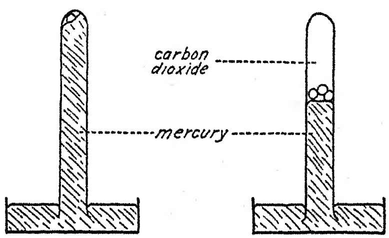


FIG. 73. A demonstration of anaërobic respiration in pea seeds surrounded by mercury. Left, at beginning; right, a few hours later.

is poisonous. Other kinds of plants, for example the yeast plant, can live and grow under anaërobic conditions.

57. **Source of Energy for Living Things.**—How do we know that energy comes from food? We know this by actual experiment.[6]

[6] A man has been placed in a closed chamber so arranged that the energy outgo from the man could be measured. This outgo consisted of heat lost, the energy lost in the evaporation of water from the body, the energy expended in work, and the energy still contained in the faeces voided. At the same time the energy supplied the man was determined. This consisted of that in the food he ate and that in the fat, muscle or other body parts which were used up during the period of the experiment. The following shows the results of a typical experiment lasting three days.

Income:	
Energy furnished in food	16,696 calories (large)
Energy from body material	69
Total	16,765

In all probability all the energy expended by living things comes from the food they consume; they do not create the energy they use; the law of the Conservation of Energy expresses the facts in energy relations for both living and non-living things.

A remarkable fact about the energy used by living things is that it can be secured only from food. We cannot substitute for the energy derived from food any other form of energy. Electricity, light, heat will not fill a man's stomach, nor supply him with the energy to move, do his work and live. It is true, however, that external heat conserves the energy of food, because less energy is required to maintain body temperature in a warm room than a cold one. If we consider then that it is established that the energy of living organisms comes from their food, from where does the energy come which is stored in the food?

We know that all food comes eventually from green plants. We know also that the food is made in the green plant by photosynthesis. In the discussion of photosynthesis it was pointed out that the construction of carbohydrates from carbon dioxide and water is a kind of work which requires energy, light being the kind of energy necessary. What becomes of the light energy required for the construction of carbohydrates from carbon dioxide and water? What becomes of the energy in any building process—the putting of bricks one upon another? It is stored in the product; and can be set free again to do work. If, for instance, the pile of bricks is jarred so as to topple over, the energy is released as sound, as heat and as mechanical energy. So in photosynthesis the light energy which is used in making carbohydrates is not destroyed, but is stored in the carbohydrates made; and it may be set free again and do more work, when the carbohydrate is destroyed.

Outgo:	
Energy lost as heat and in work	13,574
(about 1,800 calories in work)	
Energy lost in evaporation of water	2,277
Energy lost in faeces and urine	1,342
Total	17,193
Difference between income and outgo	428 calories

The average of more than fifty such experiments showed a difference between income and outgo of less than 0.1 per cent of the total. This difference is not significant, as it was equally large if alcohol were burned in a dish inside the chamber instead of food respired in a living man. Similar experiments have been performed with other animals and with plants.

We can now form a picture of the relation of living things to energy. A part of the light energy which shines on the green leaf is stored in the carbohydrates formed in photosynthesis, or in the cellulose, oil, fat, protein, and so on made from them. The rest is reflected from the leaf, passes through the leaf, or evaporates water in transpiration. Sugar, alcohol, wood, coal, petroleum, fat represent not only material substances but stored energy [7] which came originally from the sun. This stored energy may be set free by destroying the organic material, either by burning or by respiration. The green plant is the mechanism and photosynthesis the process by which the energy of sunlight is stored in foods, as well as in other materials, for example wood, which we cannot use as food.

The energy in a coiled watch spring which makes the works of the watch run came from the energy expended by the man who wound the watch. The man's energy came by respiration from the food he ate. The energy was stored in the food in the process of photosynthesis and came from the sun. So we might say that in a certain sense the sun runs the watch, and that even in such an apparently simple and commonplace event the complex processes of photosynthesis and respiration play their parts.

58. **Man's Relation to Stored Energy.**—Man is peculiar in the fact that not only does he use the stored energy of food for vital process but he uses stored energy in other ways also—for heating houses, for light, for transportation, for manufacturing. Of all living creatures man is the only one who does this. The bear, the butterfly, the tree are limited to the free energy secured by respiration from food in their bodies. Man alone has learned to release and use the stored energy of coal and oil and water power.

There was a time when all the energy which man controlled and used was only that which he himself secured by respiration from the food he ate. The pyramids were built largely by this energy. As time passed man learned to use the energy of brute animals. This energy also is secured by respiration from food. Then he developed water wheels, windmills, and finally machines by which the energy derived from coal or petroleum is used. In fact our present civilization depends upon the dissipation of large quantities of stored energy. Think but a moment of what would

[7] A chemical compound, for example sugar, is not itself energy any more than a coiled watch spring is energy. The energy is stored in the sugar.

happen if we had no automobiles, no trains, no means of heating houses, no lights but the sun and moon. What would occur to large centers of population if all sources of usable energy other than that freed in respiration were cut off tomorrow?

The ancient Greek trireme had ten marines, twenty sailors and 170 rowers. The propelling force of this capital ship of the Greek navy came by respiration from the food of the 170 galley slaves. The airplane carrier, "Saratoga," has a crew of 179 officers and 1,695 men and propelling machinery of 180,000 horsepower. This power is equivalent to that of two million galley slaves.

If we analyze all the sources of the energy which we dissipate today in such prodigal amounts in transportation, in light, in heat, in manufacturing, we find that it all comes from the sun and almost all of it has been stored for us in one organic compound or another by the photosynthesis of plants, most of it in coal or petroleum formed in past ages. What will happen when this accumulated store of energy is exhausted and we are dependent upon that which comes to us from the sun day by day? Wind power, water power and photosynthesis are the only ways by which the daily income of energy from the sun is at present made available for our use. The first is variable and erratic. All the potential water power of the United States would supply less energy than the gasoline consumed annually. Photosynthesis too is insufficient to supply our energy needs. While the green plant and the process of photosynthesis are the chief means by which solar energy has been in the past and is at present stored for us in available form, they cannot supply the energy requirements of our energy-dissipating civilization when the inherited stored energy, the "bottled sunlight" of coal and petroleum, is exhausted.

59. Respiration vs. Photosynthesis.—In many respects respiration and photosynthesis are opposite processes, as is illustrated by the following table.

Table Comparing Respiration and Photosynthesis

Respiration	*Photosynthesis*
Energy made active	Energy stored
CO_2 and H_2O formed	CO_2 and H_2O used
O_2 used	O_2 formed
Dry weight decreases	Dry weight increases
Occurs both day and night	Occurs only in light
Occurs in every living cell	Occurs in chlorophyll-containing cells only

CHAPTER VIII

THE FORMATION OF NEW CELLS

THE processes by which cells are formed are complex. So far in discussing cells we have been concerned with their size and shape, the thickness of their walls, and their larger parts, such as the plastids, nucleus, and vacuoles. In the study of cell formation the minute structures of which the protoplasm is composed must be examined, for these play definite parts in the process. Furthermore, these minute structures must be stained, since they are hardly visible in the living state; and great care must be used in the killing, sectioning, and staining [1] of the tissues, so as to preserve and make visible the protoplasm in a condition as nearly as possible like its living state.

New cells do not originate in all parts of a plant. Their formation is limited usually to certain regions, which are called *embryonic regions*. These occur in various parts of a plant (and will be further discussed when we consider *growth*). The processes by which cells are formed are essentially similar in almost all embryonic regions, and a study of any one of these suffices for all. The embryonic region found near the tip of a root happens to be the easiest to prepare for study, and is usually selected to illustrate cell formation.

At the tip of a root is a structure called the *root cap*. Within

[1] The part to be studied is killed by immersion in a liquid usually composed of a mixture of chromic and acetic acids. This solution is then washed out, and the material dehydrated by alcohol. The alcohol is replaced, first by a solvent of paraffin (xylene), then by a solution of paraffin, then by pure melted paraffin. The paraffin containing the material is solidified by immersion in cold water. A piece of paraffin is then placed in a microtome, which slices from it (and from the contained plant part) sections of any desired thickness (usually from 5 to 20 one-thousandths of a millimeter). These sections are mounted on a slide, and the paraffin dissolved off. The sections stick to the slide, and may be stained by immersing the slide in the proper solutions. Often two or three stains are used successively, one stain being absorbed by the cytoplasm, another by the nucleus and so on, so that these parts are clearly differentiated. After staining, the sections are again dehydrated, and covered with Canada balsam and a cover glass. The balsam hardens at the edges and seals the cover glass to the slide.

this is the embryonic region, where new cells are being formed. Farther away from the tip are young cells (that is, cells recently formed) which are elongating and becoming specialized. At present we are concerned only with the embryonic region. The cells of this region are characterized by their small size, very thin cell walls, small vacuoles and proportionally large quantities of protoplasm.

When we study a properly prepared section of the embryonic region of a root tip, we notice at once that some cells have a large round nucleus occupying the center of the cell (there is usually no large vacuole); while in others the nucleus is fragmented into a number of twisted rod- or ribbon-like bodies. In still others we find two small groups of these bodies, or two round nuclei. And finally in some we find a partition being formed between the two new nuclei and dividing the cell into two new cells each with one nucleus.

In fact, new cells originate usually by the division of old ones. As far as we know, cells originate *only* from previously existing cells, by their division or fusion or in some other way. Every cell that exists today is a descendant, through countless millions of cell divisions, of the first cells that ever existed, whenever that was. In the dead root tip we naturally cannot see the process of division taking place; and in living cells many of the minute structures are not visible. But in one dead and stained embryonic region we can usually find cells about to divide, cells just starting, midway in, or just finishing division, and cells "resting" (as they are said to be when not dividing) between the end of one division and the beginning of the next.

For many years after cells were discovered, their origin was unknown; and many theories were advanced to account for it. Some of these persisted even after cell division was known, and men thought that there were several kinds of origins of new cells. The best known of these supposed other methods of cell formation was known as "free cell formation." Cells were supposed to form out of an undifferentiated liquid much as crystals form from a solution. This was, of course, a result of technique much inferior to that of today.

The common method of cell division in plants and animals is called *mitosis*. This is a process which involves the formation from the nucleus of rod- or thread-like bodies called *chromosomes*.

Its details vary somewhat in different organisms. The account which follows describes mitosis as it occurs in most common plants. But before describing cell division we must study the structure of a "resting" cell—one just about to divide.

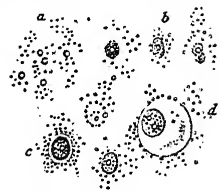


FIG. 74. Schleiden's conception of cell formation. Granules of protein (*a*) condense to form a nucleus or cytoblast (*b* and *c*), which secretes a vacuole and forms a complete cell (*d*). (From Schleiden, *Principles of Scientific Botany.*)

The large parts of a cell have already been studied; they are cytoplasm and nucleus. The cytoplasm, as seen in a prepared slide, seems to be composed of a finely granular material (the granules perhaps joined by tiny threads or films), which forms an irregular meshwork throughout the cell. In the meshes are transparent areas, which probably contain large proportions of water; these are vacuoles. There is no large central vacuole in an embryonic cell. Embedded in the cytoplasm are often various small bodies; these may be the minute granules from which plastids ultimately develop; or they may be small granules or droplets of reserve food; there are frequently thread-like bodies whose nature and activities are not well understood. The cytoplasm is bounded by a thin film called the plasma membrane, lying just within the cell wall.

The nucleus occupies the central part of the cell, and is very large when compared with the amount of cytoplasm present. It is bounded by a thin membrane, the *nuclear membrane*, which encloses a transparent material, the *nuclear sap*. Embedded in the nuclear sap are numerous small granules, some extremely tiny, others larger; these are granules of a substance known as *chromatin*. The chromatin granules are connected by a fine network of very delicate threads, composed of a material known as *linin;* the linin threads are too delicate to be seen except with the highest-powered microscopes. Also embedded in the nuclear sap are large spherical bodies called *nucleoli* (singular, *nucleolus*). In some nuclei there is only one.

Ordinarily the nucleus divides first, its division being followed at once by the formation of a partition across the cell. Cell division, then, may be separated into nuclear division and the formation of the new cell wall or membrane.[2] Since the processes

[2] By some authors the term cell division is understood to mean this last process only. It is more convenient here, however, to use it as referring to the entire series of events.

involved are complicated, they are divided for convenience into a number of "phases." It must be remembered that these are of course purely arbitrary; the cell does not suddenly change from one phase into the next; the processes are continuous, and one phase merges into the next. We might divide mitosis into fifty phases, instead of the few that are described below, if we wished to analyze it in greater detail.

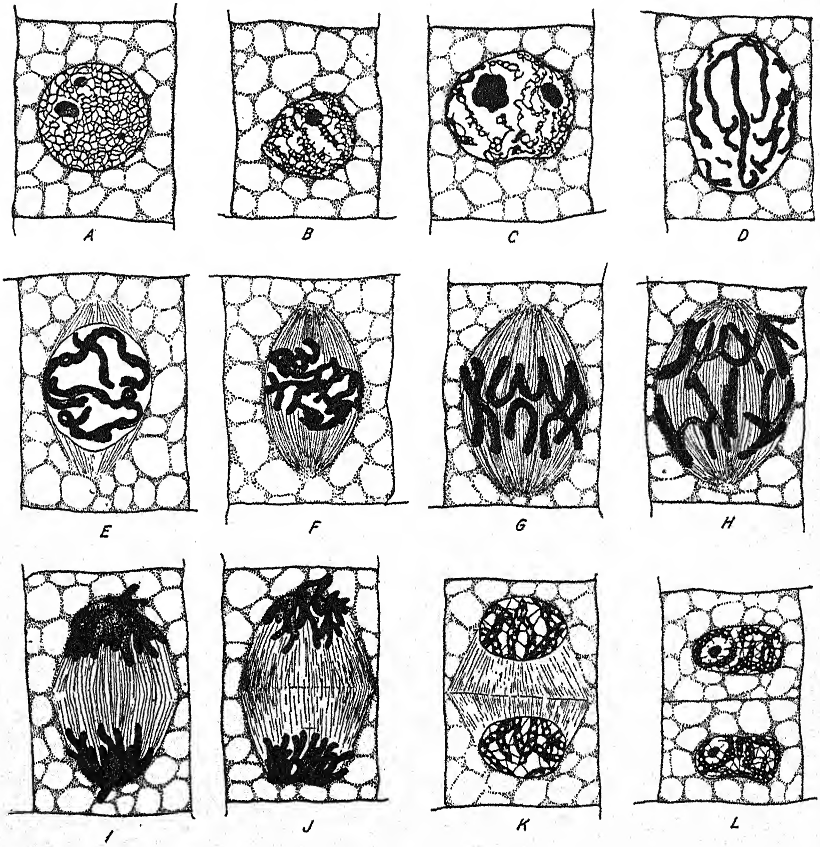


FIG. 75. Successive stages in cell division by mitosis (×1200). (Based on Sharp.)

60. Prophases.[3]—In the nucleus, the chromatin granules (with the linin) mass together so that they form a long continuous thread, the chromatin thread.[4] This is at first lumpy and irregular, but

[3] "Before" phases.

[4] Also known as the *spirem.*

later becomes smooth and uniform in thickness. Then this thread becomes segmented into a number of short pieces, the chromosomes. Of these there is a definite number for each particular kind of plant or animal—a remarkable and curious fact. In a dividing cell of corn, for instance, there are 20 chromosomes; in the hyacinth, 16; in the lily, 24; in the dog, 22; in man, 48. Finally the nuclear membrane disappears, together with the nucleoli; and the nuclear sap mixes with the cytoplasm and becomes indistinguishable from it. Thus at the end of the prophases the only visible part of the nucleus that remains is the chromatin (and linin); and this is in a much changed form.

Meanwhile, fibers begin to appear in the cytoplasm. They are formed in two groups at opposite ends of the nucleus, and just outside the nuclear membrane. The fibers seem to converge at fairly sharply defined points a short distance from the nuclear membrane, and to spread out over the latter. As the nuclear membrane disappears, the fibers grow inward toward the chromosomes (which now lie irregularly scattered across the center of the cell), and seem to become actually attached to the chromosomes, one fiber from each pole being fastened to each chromosome at opposite points. Since the fibers form a body fairly sharply pointed at both ends but wider in the middle, they are spoken of all together as a *spindle*, and singly as *spindle fibers*. The two ends of the spindle are known as the *poles*.

61. **Metaphases.**[5]—The chromosomes now become arranged more or less across the widest part—the equator—of the spindle. At least those parts of them that seem to be attached to the fibers lie across the middle of the spindle.[6] The chromosomes at this time are considerably shorter and thicker than when they were first formed. In this stage they may be seen to be split longitudinally, the two halves, however, remaining attached. This splitting may have occurred earlier, during the prophases; but it becomes clearly evident first in the metaphases.

62. **Anaphases.**[7]—Now the two halves of each chromosome separate. They begin to separate first at the points where they are joined to the spindle fibers, just as if the fibers were contracting and dragging them apart; and that is, apparently, what happens.

[5] "Between" phases.

[6] Forming what is often called the *equatorial plate*.

[7] "After" phases.

Some chromosomes are attached to fibers at or near their middles; the halves of such chromosomes separate first in the middle, remaining stuck together at the ends; and when they are entirely

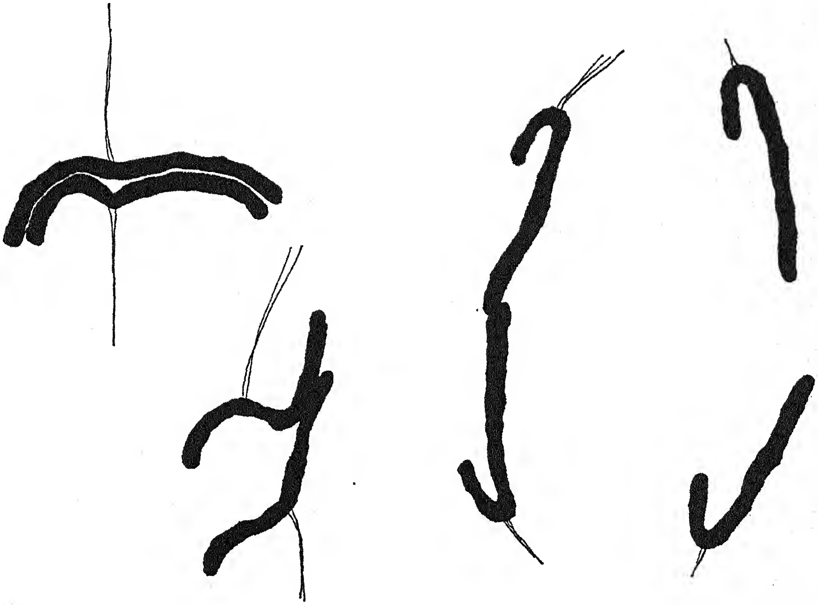


FIG. 76. Diagrams to show attachment of spindle fibers and separation of half-chromosomes in the anaphases.

separated they are often U-shaped. Others seem to be pulled apart first at their ends, and become separated as straight rods. As the apparent contraction of the fibers continues, the halves of the chromosomes move toward the two points where the fibers converge. The half chromosomes themselves, therefore, become massed n two groups, one near each pole of the spindle. The parts that are attached to fibers are usually in contact, the free ends sticking out like the rays of a star.[8] There are some fibers that are not concerned in this movement of the half-chromosomes; they extend from pole to pole, and become evident only after the half-chromosomes have been separated into two groups.

The half-chromosomes, after they are separated from each other,

[8] This is often called the *diaster*, or "two-star" stage. The word diaster is, however, confusing, since it is applied also to an entirely different stage in the division of animal cells.

are known as *daughter chromosomes*. Since each original chromosome is split and its daughter chromosomes move to opposite poles, it is evident that each group of daughter chromosomes will consist of the same number as was present in the original chromosome group of the cell. Thus each new nucleus receives and is composed of the same number of chromosomes as the original nucleus possessed.

63. **Telophases.**[9]—After the chromosomes are grouped together at either pole, they become so closely massed that it is difficult to see just what happens to them. The two groups of daughter chromosomes form at this stage what look like two densely staining solid bodies with loose ends of chromosomes projecting from them. It seems that the chromosomes in each group unite to form a chromatin thread similar to the chromatin thread of the mother nucleus.[10] Then, suddenly, each group becomes surrounded by a new nuclear membrane. The chromosomes (or the loops of the chromatin thread which they have formed) now gradually spread apart and break up; for a time they are still visible, but much obscured by transparent spaces in and between them, and by thread-like connections between them. It becomes apparent now that the chromatin is once more embedded in a clear nuclear sap; and at this time also the nucleoli reappear, at first small, later growing to their usual size. The breaking up of the chromosomes or chromatin thread continues until each daughter nucleus is once more in the condition of the mother nucleus before division began. Each daughter nucleus now resembles the mother nucleus in all respects, except that it is a little smaller and usually of a somewhat flattened shape. Increase in size takes place rapidly, and in a short time the resemblance is complete. Not only do the daughter nuclei resemble the mother nucleus in size, shape, and structure; but, as has already been pointed out, each has been formed from the same number of chromosomes as was originally present in the mother nucleus. It seems as if all the original chromatin material is accurately divided during division into two equal halves, and each daughter nucleus receives just half.

The chromosomes disappear during the resting condition. But when the daughter cells themselves begin to divide, chromosomes reappear; and of these new chromosomes there is the same number

[9] "End" phases.

[10] This stage is often called the dispirem stage.

as was present in the division of the mother cell. Furthermore, they are of approximately the same size as those of the mother cell; the chromatin material in each daughter nucleus increases in amount during the resting period. Perhaps the most remarkable fact is that there are often among the chromosomes of the mother nucleus some of recognizable shapes and sizes; and in the division of the daughter nuclei these peculiarities are exactly duplicated.

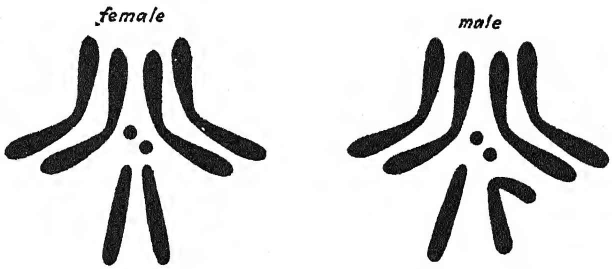


FIG. 77. Diagram showing the characteristic pairing, sizes and shapes of the chromosomes of the male and the female fruit fly, *Drosophila ampelophila.* (From Bridges, in *Genetics*, by permission.)

In the broad bean, *Vicia faba*, there are 12 chromosomes, 2 of which are about twice as long as any of the others. These large chromosomes are recognizable in *all* the dividing cells of *all* plants of this species. In the male of the common fruit fly, *Drosophila*, there are 8 chromosomes, of which 2 are very tiny, 5 of medium length, and one longer and with a hooked end. Exactly these shapes and sizes of chromosomes appear in every cell division of every male fly. It seems, therefore, that each chromosome actually *persists* through the resting stage, and is formed again at the beginning of the following division. During the resting stage, it is broken up into many chromatin granules and linin threads, and the quantity of these materials increases; but the chromosome somehow keeps its identity.

Meanwhile, changes occur in the cytoplasm. Attention has already been directed to the fact that certain fibers are not concerned in the movements of the chromosomes and extend from pole to pole. On these fibers swellings appear about midway between the two poles. These swellings grow larger, and finally touch and fuse together, forming a delicate plate extending across the equator of the cell. This is called the *cell plate*. As the cell plate becomes visible, the fibers upon which it forms become less

plain; the parts of the fibers near the poles fade out first, and finally the parts near the cell plate disappear—just as if the material of the fibers were flowing towards the equator along each fiber, and thus forming the swellings and the cell plate. The cell plate at first does not cut the cell into two—it does not reach to the cell wall on any side; it occupies only the space formerly filled by the widest part of the spindle. New fibers now make their appearance in the cytoplasm around the cell plate, and extend nearly from one daughter nucleus to the other in wide curves. These fibers repeat the process that took place in the first ones, forming swellings which fuse with each other and with the edges of the cell plate; and so the latter grows wider. The process is continued until the cell plate reaches completely across the cell, and the original cell is divided into two cells, each containing one of the daughter nuclei.

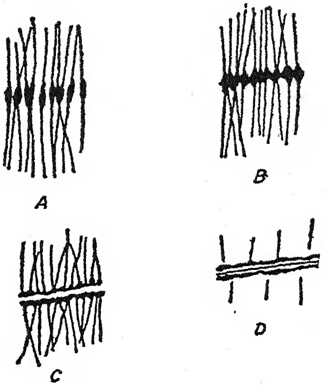


Fig. 78. Much enlarged views of spindle fibers and cell plate formation. *A*, swellings appearing on the fibers; *B*, the lateral union of the swellings to form the cell plate; *C*, splitting of the cell plate to form two new plasma membranes; *D*, secretion of a wall between the new plasma membranes. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

The cell plate is not the same as a cell wall. It is, apparently, not composed of the same materials as those of cell walls, but is still a part of the living protoplasm. Soon after it has been formed, it seems to split into two very thin films of protoplasm; and the true cell wall, consisting of non-living material, now appears between these two films. The latter become parts of the outer layers—the plasma membranes—of the protoplasts of the daughter cells. Each cell continues to form cell wall material, which is deposited against the first thin cell wall. The first thin plate is usually of a different chemical composition from the layers that are formed later, and may be observed as a distinct layer in prepared sections of old cells. It is called the *middle lamella*. Each cell later forms an additional layer of the cell wall about itself; but this layer lies between the cytoplasm and the middle lamella, which was formed by two cells in common.

Each daughter cell receives about half of the cytoplasm of the mother cell. Such cytoplasmic bodies as may have been present in the mother cell are present in at least one of the daughter cells. There is no known mechanism which distributes such bodies equally to both daughter cells (as the chromosomes are distributed); their destiny depends on their position in the mother cell. The small granules (*proplastids*) from which plastids are developed frequently split and so increase their number; and, because of their number, all daughter cells will usually contain them, if the mother cell contained any. But again there is no regular mechanism which distributes these bodies equally, so far as is known.

Two cells have now been formed, and each possesses all the structures characteristic of the mother cell before division started. The resting state—the condition of a cell between divisions—is decidedly not one of rest from anything but division. Enlargement usually follows division, until the daughter cells are about the same size as the mother cell was. Division may then begin again in each daughter cell; or one or both of them may continue to enlarge to a much greater size, and form some part of the permanent tissues of the plant. Such processes, also, as respiration, digestion, absorption of food and water, and so forth, are occurring during the so-called resting condition.

We may summarize the whole process as follows: In the nucleus, the nucleoli, nuclear membrane, and nuclear sap disappear, or at least are not distinguishable; and reappear at the end of division. The chromatin (and linin) is present throughout division, though in a changed form; during division it takes the form of chromosomes, which apparently preserve their identity from one division to the next; and each daughter nucleus receives a half of each original chromosome, and possibly a sample of each original bit of chromatin material. In the cytoplasm fibers appear and disappear, but form no permanent part of the cell. Each daughter cell receives approximately half of the cytoplasm of the mother cell, but there is no exact mechanism which divides the cytoplasm equally.

64. Other Methods of Division.—The characteristic feature of mitosis (from which, indeed, it gets its name) is the transformation of the nucleus into thread-like structures, the chromosomes. The name includes any kind of cell division in which the nucleus undergoes this change. In one kind of mitosis the chromosome number is not maintained in the daughter cell, but each of these gets one-half of the number in the mother cell. This is called *reductional*

division. It will be considered later. The more familiar kind of mitosis, which has been described above, is known as *equational division*.

In some of the simpler plants there is a different sort of cell wall formation. The division of the nucleus occurs in much the same manner as that described above. No cell plate, however, is formed. Instead a groove develops in the plasma membrane around the cell in the same plane as the equator of the spindle. This groove grows gradually deeper on all sides, exactly as if it were being caused by a thread which was being gradually tightened. Finally the groove reaches the center and pinches the cell entirely in two. As the groove is formed, the new cell wall may be deposited in it. This sort of division is known as *constriction*. It occurs also in most animals. There are also other methods of cell wall formation, which will be discussed later. Any of them may be included in the term mitosis.

Some nuclei divide in a quite different way, which lacks the formation of chromosomes, spindle, and so forth. The nucleus, apparently still in the resting condition as far as structure is concerned, becomes divided by constriction of the nuclear membrane. In this method there is, of course, no mechanism which insures that the daughter nuclei receive any particular amount or kind of

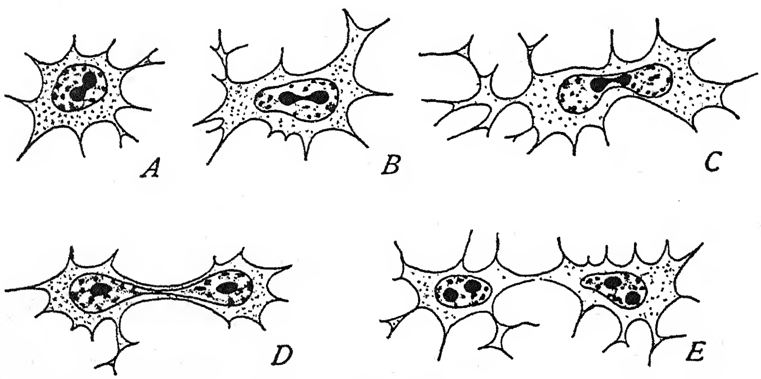


FIG. 79. Amitosis. Stages selected from fixed and stained preparation of sinew cells of mouse. (After Novikoff from Wilson, *The Cell in Development and Inheritance*, copyright 1925 by The Macmillan Company. Reprinted by permission.)

the parental nuclear substances. This sort of nuclear division is called *amitosis* ("not-mitosis"). Such a division of the nucleus may be followed by constriction of the cytoplasm; but frequently

is not followed by any division of the cell, so that the two nuclei thus formed are both enclosed in one membrane or cell wall.[11]

65. General Considerations.—It is difficult to realize that the complex and elaborate process of mitosis is a fairly rapid one. The whole series of events may occur in a little more than an hour. The prophases usually last longer than the others—the actual division of the nucleus, in the metaphases and anaphases, may occur in five minutes.

The causes of mitosis are not known. We know that some cells divide more frequently in certain environmental conditions—for example in darkness; but this is not true of all cells. We know also that certain chemical elements, commonly derived from the soil, are necessary; for instance phosphorus. It is a curious and interesting fact that mitosis often occurs in "waves" in a tissue; that is, all the embryonic cells divide approximately at the same time, so that a section made at one time may show many cells in various stages of division, while a section made at another time may show very few of the cells dividing. But of the actual mechanism, the forces and chemical reactions, which cause mitosis, we know almost nothing.

Two different sorts of seeds, planted under identical conditions, grow into quite different plants; growth occurs in both, but the details of growth are very different in each. We explain this by assuming that the two plants are formed of different sorts of protoplasm, and one sort of protoplasm is always, in general, the same for one type of plant. The same is, of course, true for animals. We can see how such a condition is possible, since all (or at least almost all) the cells of any particular type of plant or animal have descended by mitosis from the original individual of that type. And in mitosis at least parts of the protoplasm are equally divided and the halves equally shared by the daughter cells. This is true especially of the chromatin, and more or less true of the cytoplasm and some cytoplasmic bodies. It is thought, therefore, that the chromatin is especially important in the growth of the cell and thus of the whole plant, and is the chief agent in the cell which is concerned with the development by a particular organism of a

[11] In many plants the nucleus divides regularly without the formation of cell walls or even membranes, so that the whole plant may come to consist of one mass of cytoplasm containing hundreds of nuclei. Each nucleus, however, functions in connection with the portion of cytoplasm immediately around it; and this portion is really a complete cell, though not definitely divided from neighboring cells.

certain size, shape, color, and so forth. We cannot, however, jump to the conclusion that the chromatin is the *only* part of the cell that is important in growth. Certainly the cytoplasm, with its differentiated bodies, also plays a part; for no nucleus has been known to live without its surrounding envelope of cytoplasm.

All the structure of a root or stem came from a small group of embryonic cells. These groups of cells (in most plants) came originally all from one single embryonic cell—which itself came from the body of the parent individual. So that the all-important protoplasm of the cells of an organism can be traced back through cell divisions to that in the cells of its parent. What has happened is the continual enlargement of the protoplasm and its partitioning up into many cells. The protoplasm of a living thing is thus an *inheritance*—often its only inheritance—from its parent. And this protoplasm is of a certain type which is more or less constant from generation to generation. Commonly organisms are said to inherit certain characters from their parents; for example the red color of their flowers. It is evident that this is not strictly accurate. When we say that a son has his father's blue eyes, we do not mean this in a literal sense. The character was not handed on; but a certain kind of protoplasm was; and this kind of protoplasm grew in such a way that blue eyes were the result. The character of the offspring frequently (though not necessarily) *resembles* that of the parent; but what the offspring *inherited* was a bit of protoplasm of a certain type which developed the characters responsible for the resemblance.

A marvelous and complicated process, repeating itself time after time with wonderful precision—such is mitosis. In the growing ends of twigs and roots, in the layer of cells under the skin of a human hand, mitosis is constantly taking place. The number of times that mitosis occurs in the development of a familiar living organism is almost unbelievable. In an average-sized Irish potato there are about 3,000,000,000 cells; which means that cell division occurred that many times in the development of the potato. In the trunk alone of one of our great trees of the western United States, there are over *ninety quadrillions* of cells. Mitosis has been repeated in all its details, prophases, metaphases, anaphases, telophases, without a mistake, that number of times. And upon mitosis depend growth, both the amount of growth and the kind of growth; reproduction; and heredity.

CHAPTER IX

Growth

One of the most familiar characteristics of living things is that they grow. The child grows into a man, the puppy grows into a dog, the corn grain grows into a large corn plant. Each spring (in temperate climates) new leaves and branches grow from the older parts of trees, and the underground stems of grasses send up new erect stems and leaves. Although growth is a familiar phenomenon, few analyze the process and attempt to determine what it is or how it occurs or to answer any of the other fundamental questions [1] which might be asked about it.

66. What is Growth?—Most people would probably answer this question by saying that when anything grows it gets bigger. But that is evidently not all we include by the term growth. A dog is not merely an enlarged puppy, and a man is more than an overgrown infant. The body structure, proportions and functions change as an individual grows. This phase of growth is commonly called *differentiation* or is referred to by the term development, and in all but the simplest living creatures it is intimately connected with increase in size. We can illustrate what growth is by considering some examples.

One simply constructed living thing is a creature called the amoeba, which consists of a bit of naked protoplasm from 0.03 to 0.3 mm. in diameter. Microscopic examination shows that the amoeba is a single cell made up of a nucleus and its surrounding cytoplasm. Because there is no distinct cell wall this organism is placed in the animal kingdom. The amoeba lives in water and

[1] One of the most important things for any one to learn is the types of questions which may be asked about any subject. All of the questions which may be asked may be grouped under those which inquire *what* it is (for a person, *who*), *where* it is, *when*, *why* and *how*. In addition to these groups of fundamental questions, we can inquire what the relation of the particular subject is to others, that is, what is its significance or importance. So we may inquire: What is growth? Where does it occur? When does it occur? How does it occur? Why does it occur? And what is its significance or importance? If we answer these questions completely and thoroughly, we omit nothing of importance that might be said about growth. The common tendency of the untrained mind is to discuss at length facts which are concerned with one of these types of questions and to fail to consider the others.

moves from place to place by a sort of flowing process; and as it moves about in the water it flows around bits of plant or animal material which it digests and which are its food. If the food is sufficient in amount the amoeba grows larger, but not indefinitely. As it reaches a more or less definitely limited maximum size it divides into two approximately equal parts, each with nucleus and cytoplasm, which flow away as independent individuals capable of

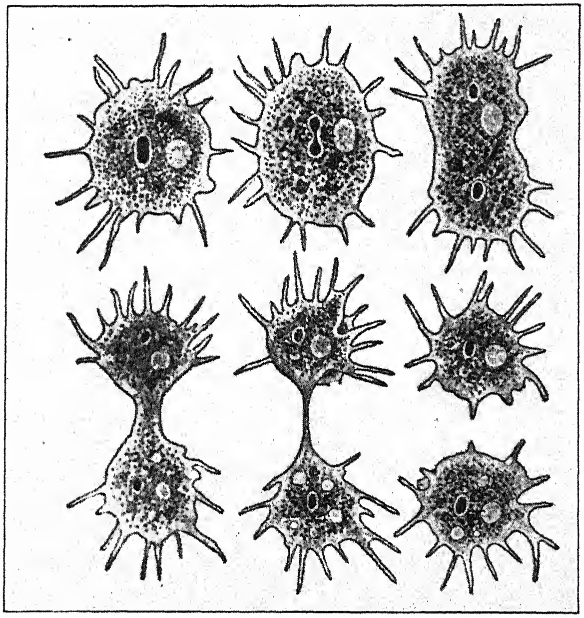


FIG. 80. *Amoeba polypodia* in successive stages of division. The light spot is a vacuole; the dark spot is the nucleus. ×200. (After Schultze from Parker and Haswell, *Textbook of Zoology*, copyright 1910 by The Macmillan Company. Reprinted by permission.)

growing larger and dividing again. If the amoebae should stick together as they grow, instead of separating and proceeding on their separate ways, a mass of protoplasm large enough to be seen by the unaided eye would in time develop. Some organisms do grow in this way. Plants called the slime molds, which are found flowing over the surface and in the crevices of decaying wood or leaves, begin their lives as individuals much like the amoeba in size and structure. As the slime mold grows, the protoplasm

increases in amount and the nuclei divide; the nuclei and their surrounding cytoplasms, however, do not separate from one another and go their several ways, but remain together. Thus the slime mold gets larger and larger until it may consist of a mass of protoplasm several square inches in area.

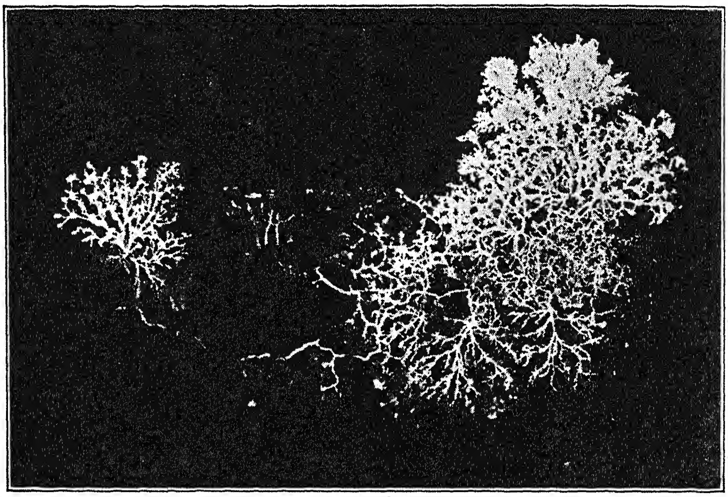


FIG. 81. A slime-mold (Myxomycete), *Fuligo septica*, growing on the inner surface of a glass jar. About natural size. (From Gager, *General Botany*, P. Blakiston's Son & Co.)

Most living things with which we are commonly acquainted do not grow into mere masses of jelly-like protoplasm, as does the slime mold. They have leaves and roots and stems, or legs and heads and eyes. This process that is something more than mere increase in size, which results in the definite shapes and parts that most organisms have, we refer to as differentiation. In the amoeba growth is almost entirely increase in size. The growth of some other living things is largely differentiation. Usually, however, both occur together.

How growth takes place and when and where it occurs will become clear in a description of the growth of a seed plant. For convenience the growth of the primary body and of the secondary body will be discussed separately. The latter includes all these parts and tissues which originate from cambium layers—all other parts and tissues make up the primary body.

Growth of the Primary Body

A seed plant usually originates as a single cell in a part of the flower called the *pistil.* This cell is usually microscopic in size, and structurally much like an amoeba, though not motile. It increases in size and divides into a chain of cells. One of these, located at the end of the chain, divides in several planes, the

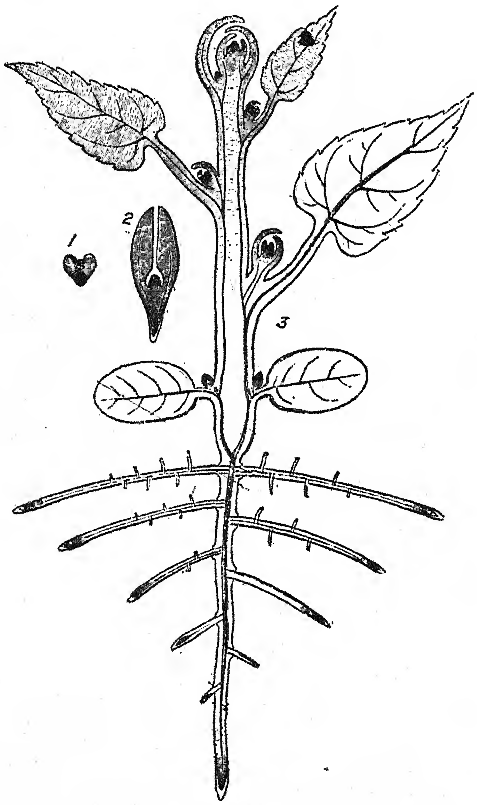


FIG. 82. Diagrams of a dicotyledonous plant at three periods of development. The growing regions are shaded. *1*, a young embryo; *2*, a mature embryo; *3*, the young plant. Notice increase in size and differentiation and the eventual limitation of growth regions as the plant grows. (From Sachs, *Physiology of Plants*, Clarendon Press, Oxford.)

number of cells and the size of the whole body increasing in the process. Some of the cells so produced make up the seed leaves, some a young stem, and some the beginnings of a root, the whole

comprising an embryo plant which lies within the seed. Both increase in size and differentiation occur in this period of the growth of the original cell into the embryo plant.

As the seed matures, the embryo plant ceases growth. When the seed is planted it absorbs water, and the foods stored in the seed are digested and are used by the young plant, which has resumed its growth, to construct new body parts and to supply energy. The cells of the embryo plant increase in size and in number, and the seedling bursts its way out of the seed, establishing its root system in the soil and its stem and leaves in the air. From this time growth is largely limited to particular parts of the plant body. In the primary body these regions are found at the tip of each root and rootlet, at the tip of the main stem and of each branch, in the pericycle, and in the buds. The growth of these regions results in increase in length and in the formation of leaves, flowers, fruits and seeds and of root branches and stem branches. Growth occurs in all of these regions in the same fundamental way, which can be illustrated by a description of the growth in length of the root.

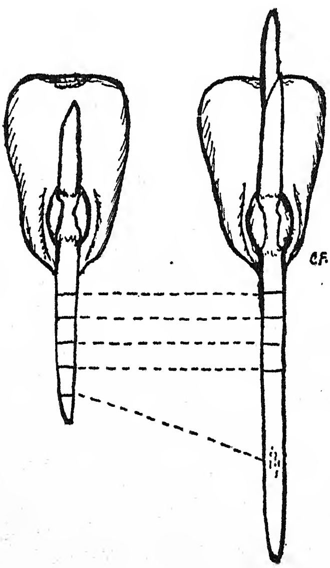


FIG. 83. A germinating corn grain with root marked with ink lines, and its appearance 12 hours later.

67. Primary Growth of Root.—If we mark a root of a germinating corn grain or other young plant with crosswise ink lines a millimeter apart and place the seedling under conditions suitable for growth, we can observe by the spreading apart of the lines which part of the root grows in length. We find that the root does not increase in length all over uniformly. Only the lines on the two or three millimeters nearest the root tip spread apart, the others remaining unchanged. This limitation of growth in length to the terminal two or three millimeters of the root is an important adaptation. If the root increased in length throughout, the root hairs and branch roots, fixed as they are in the soil, would be torn loose from the main root as it lengthened. And if the

increase in length occurred elsewhere than at or near the tip, the pliable root would not penetrate the tough soils. This can be demonstrated by comparing the readiness with which a piece of copper wire if grasped close to the tip can be pushed into a tough material like putty with the difficulty when it is grasped further back.

If now we examine a longitudinal section of a young root, or a

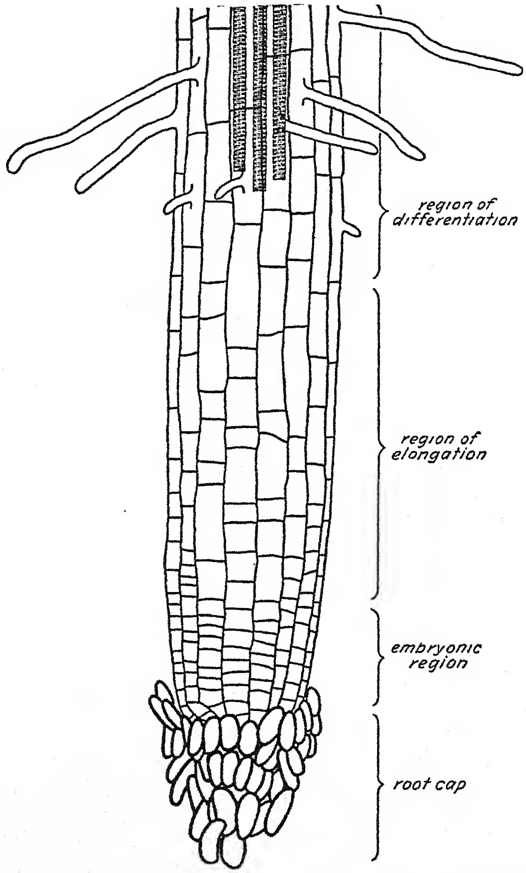


FIG. 84. A diagram of a portion of the root tip of red top, *Agrostis alba*. Compare with Figs. 25 and 85.

living root (such as that of a grass seedling) so thin that the cells may be easily seen, we find that the cells in the tip are very small

and about equal in all dimensions, but that those farther back are much longer than they are wide. Evidently the increase in length of the root is caused by the elongation of the cells just behind the root tip.

These cells do not continue to elongate indefinitely. They differentiate and acquire certain characteristics, according to their position in the root. Those on the outside become epidermal cells, many of them with those projections which we call root hairs. And others become the other specialized cells which we have studied in a cross section of the root in the region of the root hairs.

Elongation of the root, however, does not stop when the elongating cells have become mature. New cells are formed by division near the root tip; some of these elongate, and the root tip continues to be pushed forward.

On the extreme tip of the root, in front of the dividing cells, is a group of cells which covers the tip as a thimble does the finger. This *root cap* is formed from some of the offspring of the dividing cells within it, and is constantly being added to by division. It never becomes any larger, however, for the older cells on the outside are constantly being worn off by the pressure of the soil, or by other outside agencies, about as fast as new cells are added by the dividing cells on the inside.

We can therefore divide such a root, lengthwise, into several regions, according to the activities of the cells. On the extreme tip is the root cap. Immediately behind this is the region of dividing cells, the *embryonic region*. Just behind this is the region of *elongation*, where some of the daughter cells of the embryonic region are elongating. Behind this is the region of *maturation* or *differentiation*. And finally there is the part of the root which is mature and differentiated. In the embryonic region the cells are about as long as broad, densely filled with protoplasm, in which the vacuoles are numerous and small and the nucleus occupies the central part of the cell. As the cells elongate, the vacuoles fuse and enlarge, until eventually there is in each cell a single large central vacuole; the cytoplasm is in such a cell a thin layer lining the walls and containing the nucleus which has been pushed to the side by the enlarging vacuole.

It must be emphasized that there are no sharp lines between these regions. At the place where embryonic and elongation regions meet, some cells are dividing or about to divide, others

just beginning to elongate; and they can seldom be distinguished by the eye. Farther back are cells a little longer, and farther still are cells obviously elongating. Even in the region of elongation

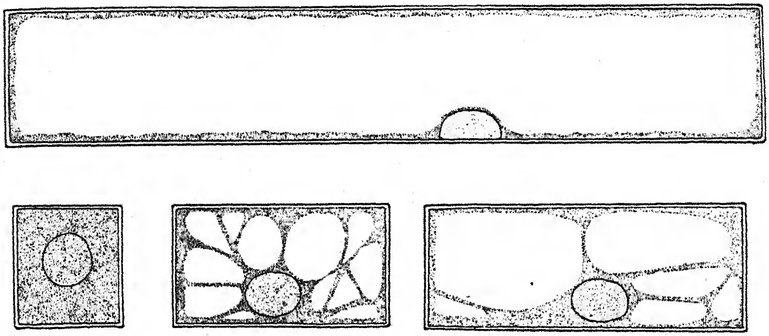


FIG. 85. Living cells from the root of a seedling of red top, *Agrostis alba*, showing elongation. The cell in the lower left corner is from the embryonic region (compare Fig. 75, which shows a similar cell killed and stained). The others are from the region of elongation, and show various stages in the formation, enlargement and fusion of the vacuoles.

some cells continue to divide, while their neighbors elongate without division. Similarly the region of differentiation is not sharply limited. In some roots, such as those of corn, some differentiation is visible even in the embryonic region, which can be separated into a surface layer a single cell thick, the *dermatogen*, a central core, the *plerome*, and the tissue between these, the *periblem*. The cells of the plerome develop to form the parts of the stele, those of the periblem differentiate into the cortex, and the dermatogen forms the epidermis.

The differentiation of the cells is a gradual process. Those cells which eventually form the xylem vessels first elongate and enlarge somewhat in diameter, then the end walls of a series dissolve away and the side walls develop thickenings of various types. Some of the cells in the region of differentiation remain undifferentiated—we have called them parenchyma cells. Differentiation is also an orderly process. The cells of the dermatogen always form epidermis, never endodermis, nor pericycle, nor xylem. Xylem vessels never differentiate elsewhere than in the stele.

68. Branch Roots.—Above the region of elongation small groups of the pericycle cells start to divide, some of the cells thus formed

elongate and differentiate, and branch roots thus appear. The branch roots are formed *within the cortex*, and push out through it, crushing and destroying certain of the cells in their path.

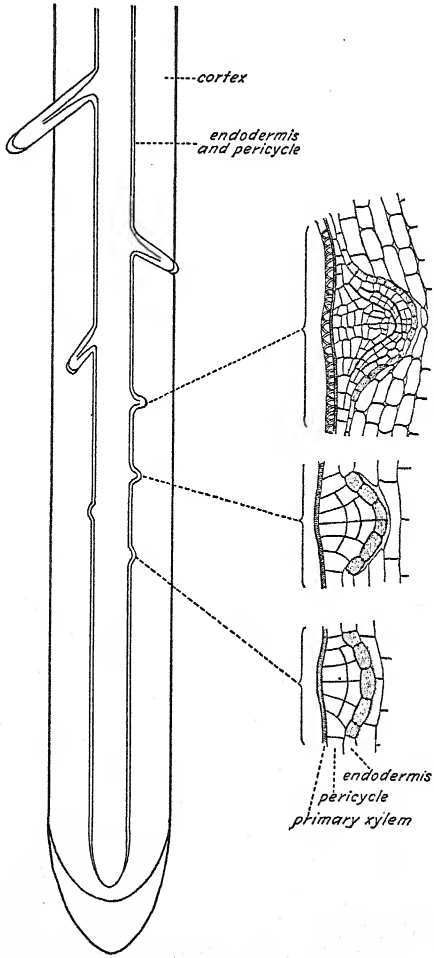


FIG. 86. Origin of branch roots. Left, diagram of longitudinal section of root showing branch roots at various stages of development. Right, detailed drawings of early stages of branch root development. (Detailed drawings after Van Tieghem and Douliot.)

The primary growth of the root is therefore far from simple. It is an ordered series of events which involves increase in number

of cells, increase in size of cells, and differentiation of cells. It results in increase in size and increase in complexity.

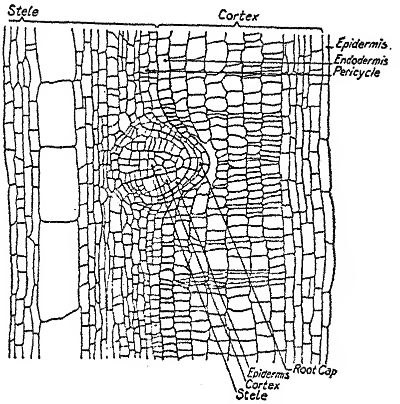


FIG. 87. A longitudinal section of a root, showing a lateral root pushing out through the cortex. The formative regions of the branch root are labeled according to the mature regions into which they develop. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

69. Primary Growth of Stem.—Growth in a stem tip occurs in much the same manner as in a root tip. At the tip of the stem there is an embryonic region, which changes into a region of elongation which may be several centimeters in length, instead of 2 or 3 millimeters as in the root. The region of elongation grades into a region of differentiation where the various permanent tissues of the primary stem are organized. This occurs gradually. In most herbaceous stems the cells in certain parts of the region of elongation lengthen and form strands (*procambial strands*). The cells of these strands differentiate to form the fibro-vascular bundles. In many woody stems, a procambial cylinder is formed, the cells of which differentiate to form a cylinder of xylem surrounded by one of phloem. The xylem and phloem are separated by a cambium layer. There is no cap over the tip of the stem, as there is in a root. At the surface small groups of embryonic cells divide in a plane parallel to the length of the stem, elongate at right angles to this plane, and so come to project sideways from the stem tip. These small plates of cells, which are young leaves, first grow curved and arch up around the stem tip and protect it. Then they spread out, as they become still larger, and become the mature leaves.

In a longitudinal section of a stem tip we can see leaves in all stages of development successively from the tip backwards. In

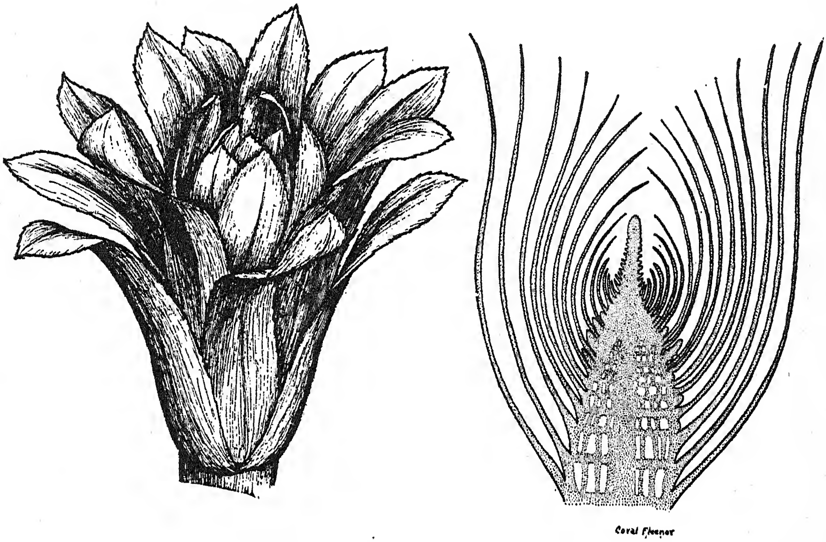


FIG. 88. An *Elodea* bud and a diagram of a longitudinal section through it, showing the embryonic region of the stem tip surrounded by young and older leaves.

their young stages, when they are curved over the stem tip, they are very close together. But as the cells of the stem elongate they become farther apart. The part of the stem, at and near

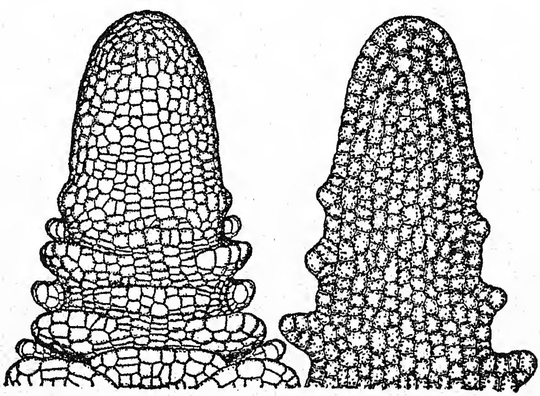


FIG. 89. The stem tip in an *Elodea* bud; exterior view and longitudinal section. ×150. (After L. Kny.)

the tip, where the internodes are still very short, and the rudimentary leaves which curve forward over the tip, are together known as a *bud*.

70. **Buds.**—At the tip of every stem is a terminal bud [2] (in some

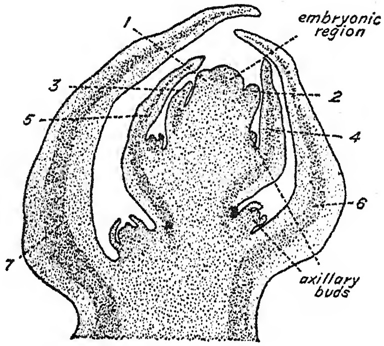


Fig. 90. A diagram of a longitudinal section of the terminal bud of *Aristolochia.* No cells are shown. The embryonic leaves (leaf primordia) are numbered in the reverse order of their formation, 1 being the youngest and 7 the oldest. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

kinds of plants, two). In trees, which live over winter, the outer leaves of the bud become scale-like and hard, and fit very closely; they are often glued together by sticky secretions of the cells. Growth ceases during the winter; and the young, undifferentiated cells of the bud are protected against evaporation and mechanical

Fig. 91. Bud scales of an ash (*Fraxinus*) showing the gradual transition from the outer scale (at the left) to one of the innermost scales (second from the right) and finally to one of the foliage leaves within the bud. (Redrawn from Gager, *General Botany*, P. Blakiston's Son & Co.)

[2] The terminal bud of some woody plants, for example the elm, hackberry, red bud, mulberry and osage orange, drops off after the completion of growth in the spring, leaving a scar at the end of the stem. These plants at that time have no terminal bud. New growth takes place from an axillary bud, which is usually very near the end of the stem and without careful examination may appear to be a terminal bud.

injury by their covering of *bud scales.* Such buds are called *winter buds* or *resting buds.* When spring comes water enters the cells

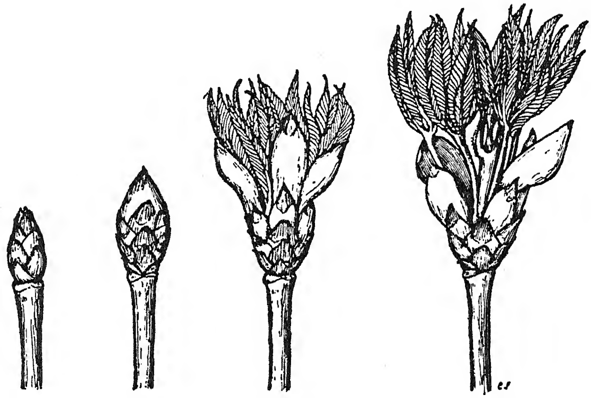


FIG. 92. A series of stages in the growth in the spring of a bud of buckeye, *Aesculus glabra.*

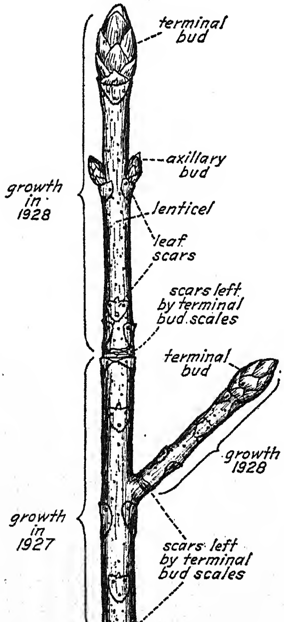


FIG. 93. Twig of buckeye, *Aesculus glabra,* showing two years' growth.

within, growth begins again, and the pressure forces apart the bud scales. These fall off, leaving a ring of scars around the stem, which marks the beginning of that year's growth. The age of a twig may be estimated by counting the number of such rings on it.

In the axils of the leaves are small groups of embryonic cells which themselves become buds. These *axillary buds* may continue growth at once; or may lie dormant until next season (as in most trees); in either case, when they do grow, they form branches. The origin of branches is therefore usually in the axils of leaves; and underneath the point where a branch joins the main stem may usually be found, for a time, the scar left when the leaf which was there dropped off.

The relative growth of terminal and axillary buds varies in different plants. In the elm the bud nearest the stem tip

grows fastest, the next one to this next fastest; and so on; so that we have long main branches with many side branches evenly dis-

Fig. 94. Three stages in the growth of the buds of an elm, *Ulmus americana*. At the right, early spring; flower buds swelling, vegetative buds still dormant. Center, flower buds open. Left, flowers have formed fruits, which have fallen; axillary and terminal vegetative buds have developed branches with leaves and new resting buds. One year's growth is shown in the right-hand figure, two years' growth in the left-hand figure.

tributed. In the pine, a cluster of buds is produced at the end of each year's growth. The terminal one develops strongly, the others not so strongly; so that the tree has a strong upright main stem with whorls of lateral branches at fairly regular intervals. In the buckeye, the axillary buds are opposite each other, in pairs; and of each pair one usually develops much faster than the other, so that the branching is irregular and one-sided. In some plants, such as the elm and *Coleus*, the axillary buds usually develop and a much-branched stem is the result. In other plants the axillary buds may remain dormant for many years.

If the terminal bud is removed, the axillary ones frequently develop to a greater extent; and a bushier type of growth is the

result. The removal of the terminal bud may also cause the development of dormant buds and the formation and growth of *adventitious buds*. Buds which develop anywhere on the plant except in the axils of the leaves or at the stem tip are called *adventitious buds*. These facts are used in the practice of pruning fruit trees and other cultivated plants, in order to bring them into a desirable shape, and in the production of "pollarded" trees. If most of the stem of a plant is cut off, adventitious buds may develop; that is, groups of hitherto undifferentiated cells may become buds at or near the point where the stem was cut. This is illustrated by the frequent growth of branches from the old stump of a tree that has been felled. In a plant growth may occur in several regions; and, if stopped there by outside agencies, may begin again in some other place.

FIG. 95. A pollarded willow. Numerous branches developed from adventitious buds when the upper end of the stem was cut off.

Flowers, which are themselves specialized branches, originate in buds; sometimes they are contained within the same bud scales as the *vegetative* (non-reproductive) buds; sometimes they are separate. In the elm, *flower buds* are formed usually in the axils of the lower leaves on each year's growth. There are, therefore, towards the base of the year's growth on the elm a series of scars, and no branches, showing where the flowers and fruits were attached before they dropped off. The form of the mature plant is thus largely dependent upon the activities of the various buds—terminal, axillary or adventitious; resting, dormant, vegetative or flower.

71. Plant and Animal Growth.—One of the great differences between plants and the higher animals is that growth in size continues during the life of the plant. If all the embryonic cells of a root tip were to elongate and differentiate, instead of only the rearmost of them, the growth in length of that tip would cease. This sort of thing does actually happen in most parts of an animal; consequently it reaches its mature size and gets no larger. Another

great difference is the retention by plants of so many undifferentiated cells, which often, under abnormal conditions, for example those produced by wounding, become embryonic regions. Processes by which a plant forms new parts that have been removed are called *regeneration*. (Some of the so-called "lower" animals also have the power of regeneration.) But when a removed part of a plant itself regenerates all missing parts, the process is classed under reproduction rather than under growth, since a complete new individual has been formed.

72. **Growth of Leaves.**—As stated above, leaves originate from a group of embryonic cells originally belonging to a stem tip. The cells undergo the usual processes of growth, but finally, in most leaves, *all the cells mature;* so that growth ceases. The leaf reaches a definite size, and then stops—it does not, like a root or stem, continue to increase in size. In this the growth of a leaf resembles the growth of an animal organ.

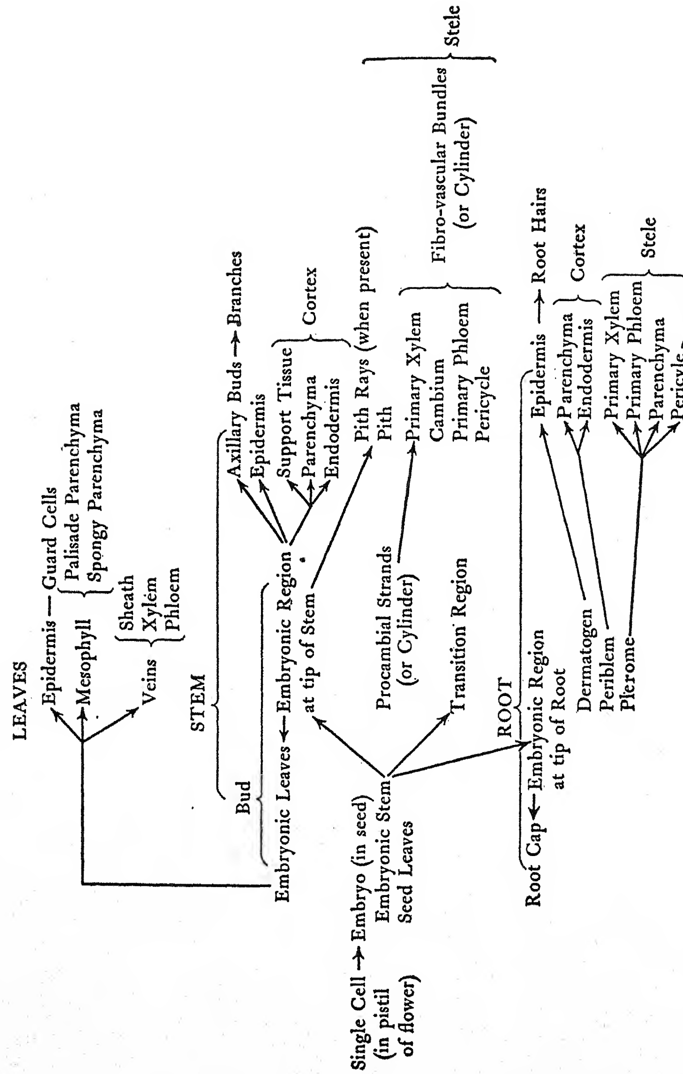
73. **Summary of Primary Growth.**—The growth of the primary body of a familiar plant is a process which involves the cells, which illustrates again the importance of the cell theory. By the division of cells, the enlargement of cells and their differentiation, the parts and tissues of the primary body develop. These may be briefly summarized in the accompanying diagram.

Growth of the Secondary Body

Besides increasing the length of stem and root, the enlargement of the cells formed in the embryonic regions of the root tip and stem tip increases to some extent the diameter of these organs. Other embryonic regions are responsible for further increase in diameter and for the development of what is called the *secondary body*. The secondary body consists of *secondary xylem*, *secondary phloem*, *vascular rays*, and *periderm*.

74. **The Formation of Cambium.**—In the region of differentiation of the root of a dicotyledonous plant the parenchyma cells located in the angles of the xylem and between it and the phloem become embryonic. There are just as many of these regions as there are angles of the xylem. The pericycle cells at the points of the xylem also become embryonic and these embryonic regions are adjacent to those mentioned above, so that a continuous embryonic layer is formed all around the xylem. This is the root cambium.

In the region of differentiation of the stem the part of the



THE FORMATION OF THE PRIMARY BODY IN A DICOTYLEDONOUS PLANT

procambial strands lying between the xylem and phloem does not differentiate but is embryonic, forming the fascicular cambium. A layer of cells situated in the pith rays (when these are present)

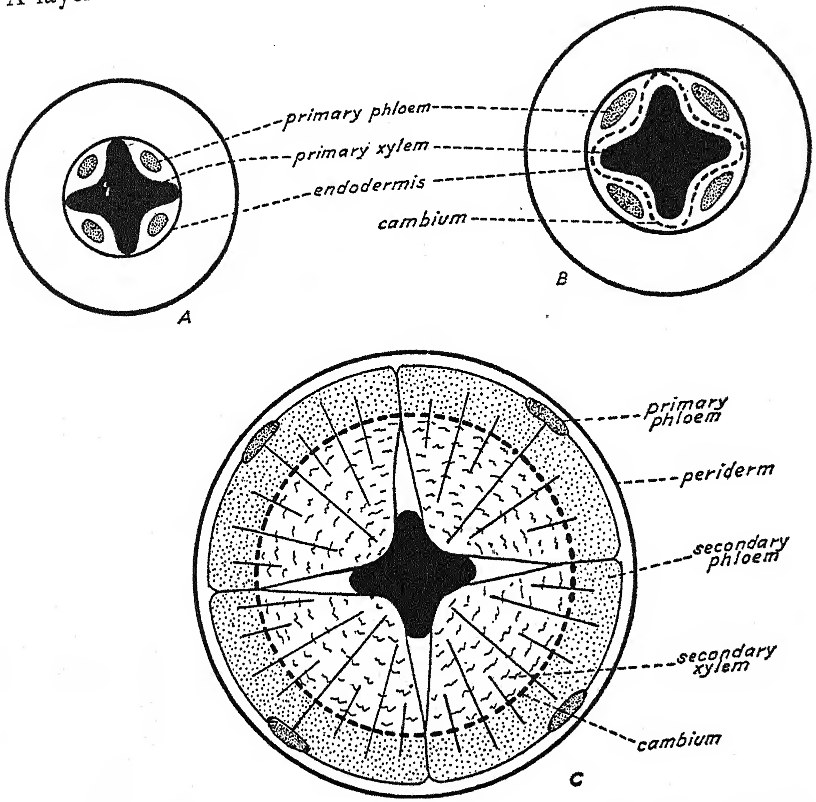


FIG. 96. *A*, diagram of a cross section of the young dicotyledonous root before the cambium is formed. *B*, the same with cambium differentiated. *C*, after secondary xylem and phloem have been formed. The formation of a periderm later has resulted in sloughing off of the cortex. (Redrawn from Bower, *Botany of the Living Plant*, copyright 1919 by The Macmillan Company.)

between the bundles and connecting the fascicular cambium of one bundle with that of another also becomes embryonic, forming the interfascicular cambium.

75. **Cambial Growth.**—The cambium layers of the root and of the stem developed in this way form a continuous sheath of embryonic tissue which encloses the xylem and extends from the region

of differentiation of the stem to the region of differentiation of the root. The growth of the stem cambium and root cambium forms the secondary xylem, secondary phloem and vascular rays.

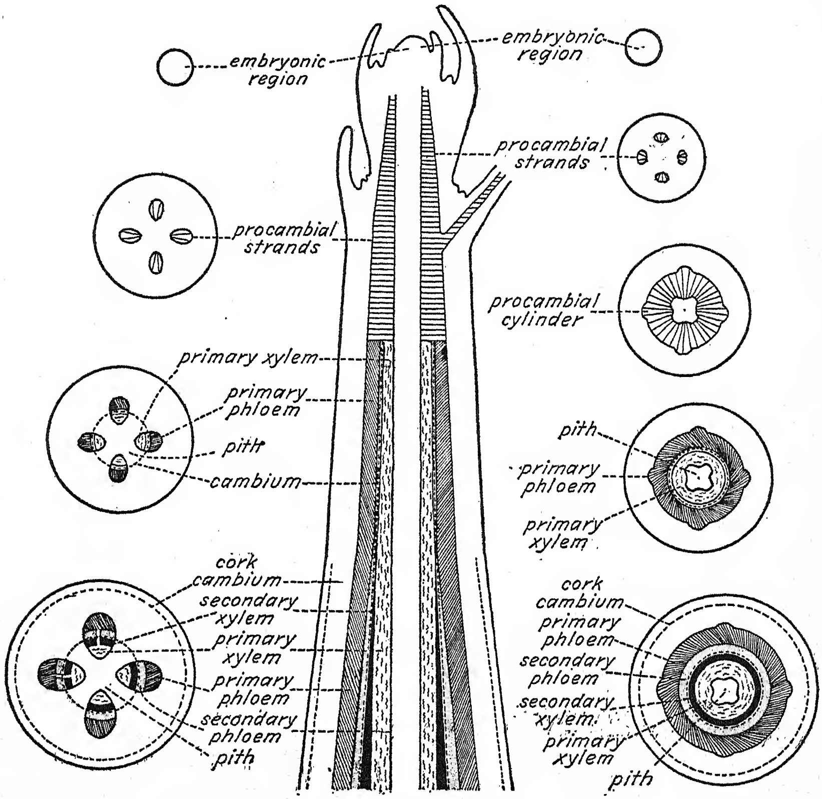


FIG. 97. Diagram of longitudinal and cross sections of typical dicotyledonous stems, showing primary and secondary growth. Left, cross sections of stem with procambial strands; right, cross sections of stem with procambial cylinder. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

A single fascicular cambium cell forms, by division, two cells, one next the xylem, the other next the phloem. Of each pair of cells formed by division, one remains embryonic, the other undergoes the remaining phases of growth—enlargement and differentiation. The one next the xylem may enlarge, and then undergo those changes in shape and in thickness of wall and in content which

transform it into a xylem vessel or a xylem fiber. The other cell remains embryonic and again divides. Of the two new cells now formed, the one next the phloem may enlarge and differentiate into a new sieve tube or companion cell, the one next the xylem

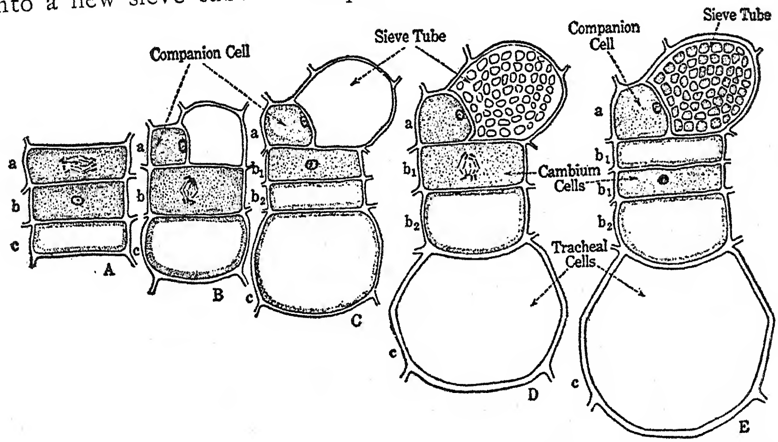


FIG. 98. Stages showing the differentiation of cambial cells. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

remaining embryonic. The new elements formed by the cambium constitute the secondary xylem and the secondary phloem. The interfascicular cambium also produces new xylem and phloem in exactly the same way, so that the new xylem and phloem do not merely add to the vascular bundles, but form continuous cylinders, one within the other. The innermost cells of the pairs of cells formed by division differentiate more frequently than the outermost, so that xylem is formed more rapidly than the phloem, and the bulk of most old stems or roots comes to be xylem or wood. At certain points the cambium cells mature into rectangular cells which form distinct lines in the xylem and phloem, radiating from the center outwards. These lines of cells are called *vascular rays.*[3] They conduct materials laterally and store food. The pith does not increase in size. Its cells may die, forming a small hollow; or their walls may become hardened and like those of the wood cells by which they are enclosed.

Of the cells formed by the division of the cambium, those next

[3] Also commonly called medullary rays.

the xylem differentiate into secondary xylem or vascular rays, those next the phloem into secondary phloem or vascular rays, and those between remain embryonic. The cambium therefore forms a cylinder of embryonic tissue which is located between the xylem and phloem and which increases in diameter and maintains its position as the xylem increases in diameter. Theoretically the cambium layer is but one cell thick. Under the microscope three,

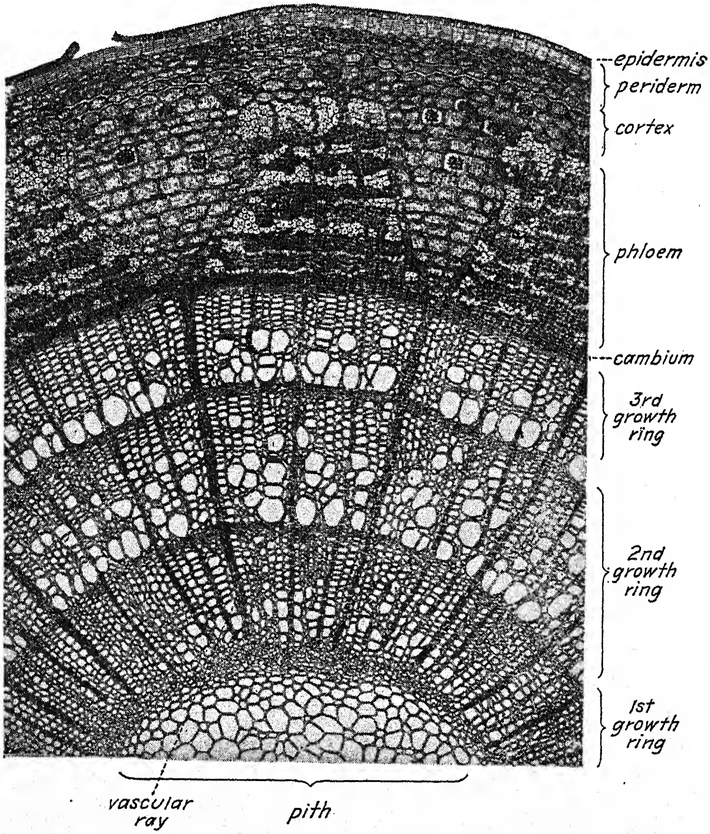


Fig. 99. Portion of a cross section of a three-year-old stem of basswood (*Tilia*). (After L. Kny.)

four or five rows of cells in the region of the cambium appear undifferentiated and it is difficult if not impossible to distinguish between them. The youngest xylem is that next the cambium, the oldest is that nearest the center of the stem and farthest from

the cambium. The youngest phloem is that next the cambium and the oldest is that nearest the outside of the stem and farthest from the cambium.

76. **Growth Rings.**—In trees of the temperate zone, which live for many years, there is often a difference between the wood formed in the spring and that formed in the summer. The cells formed in spring are large, and those formed later are smaller, those formed in the summer being comparatively very small. Then comes the dormant period of winter when no growth occurs. The next spring a layer of large cells is again formed next to those of the preceding summer. The contrast here enables one to see in a cross section just where each year's growth began and ended. Each year's layer of wood, consisting of large cells and small, and every size between in regular order, is called a *growth ring*. When the trunk of a tree is cut across, the growth rings are visible as a number of concentric bands; the age of the tree may thus be estimated. It is interesting to notice in the cross section of a tree that some annual rings are broader than others—more growth took place during some years than during others; and these differences may often be correlated with differences in rainfall and temperature during the years concerned. By counting in from the outermost ring one can determine the date of any particular ring; and from the Weather Bureau's records the rainfall and temperature conditions for that year can be obtained. In warm climates growth rings may be caused by alternation of wet and dry seasons or other factors. In southern California the lemon tree forms three growth rings each year.

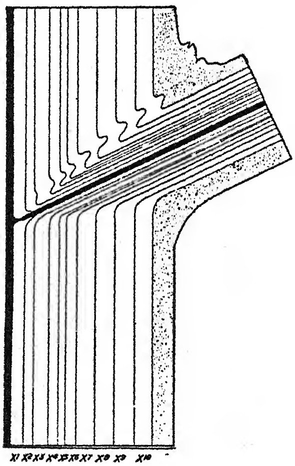


FIG. 100. *A*, diagram illustrating the burial of branch bases by secondary xylem. The phloem is pushed away from the buried portion and thrown up in the crotch angle into folds. The cambium layer also is distorted in position. The pith is shown in solid black; the phloem and cortex stippled. x^1 to x^{10}, successive growth rings. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N.Y.)

77. **Knots.**—Branches usually originate, as has been already mentioned, from axillary buds formed in the primary embryonic region at the tip of the stem.

These branches are parts of the primary body. As the diameter of the main stem is increased by secondary growth the bases of the branches which also undergo secondary thickening become surrounded by and embedded in the new layers of cells. When the main stem is cut longitudinally these enclosed branches are cut crosswise and form knots.

78. Grain of Wood.—The other lines and patterns in lumber are caused mostly by the growth rings and vascular rays, the kind of

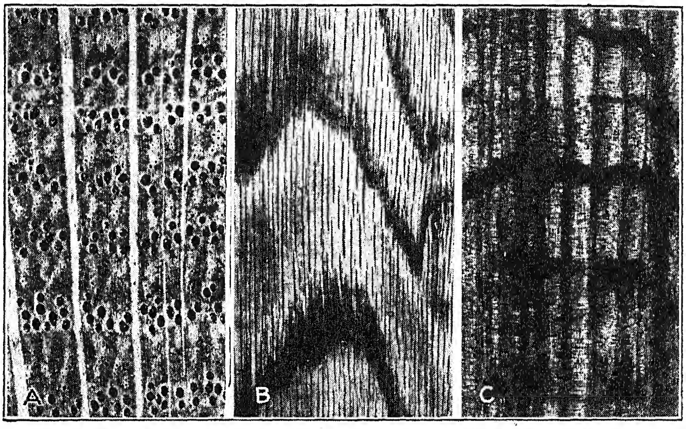


FIG. 101. Sections of the wood of red oak, *Quercus rubra*. *A*, cross section ×3; *B*, tangential section ×2/5; *C*, radial section ×2/5. Five growth rings and parts of two others are shown in the cross section. The black spots are the large vessels in the spring wood; the white streaks perpendicular to the growth rings are vascular rays. In the tangential section the ends of the vascular rays appear as narrow vertical black streaks. The spring wood (dark) of three growth rings is shown, the summer wood being light. In the radial section eight growth rings and parts of two others are shown; the spring wood is the dark vertical streaks; the vascular rays, now seen from the side, are almost black in the figure and are perpendicular to the growth rings. (Courtesy of the Forest Products Laboratory, United States Department of Agriculture.)

pattern depending on the direction of the cut. It is these marks in wood that are commonly known as the *grain* of the wood. As the tree is rarely exactly straight, various combinations are obtained of curves and lines representing growth rings and vascular rays. The practice of "quarter-sawing" oak gives a particularly desirable grain, because the trunk is sawed radially, exposing the broad side of the vascular rays which appear as flakes in the board. By this method of cutting much wood is wasted, and quarter-sawed

oak is correspondingly expensive. "Curly Maple" and "Bird's-eye Maple" have curious and ornamental grains caused by irregularities in the growth of the xylem of the tree.

79. **Periderm.**—As the cambium of the root or stem grows changes take place also in the bark. The bark of a stem or a root includes all tissues outside of the cambium. In the primary body it is made up of phloem, pericycle, cortex, and epidermis. As the plant gets older a layer of cells somewhere in the bark, usually in the cortical parenchyma, becomes embryonic, forming what known as the *cork cambium*. This layer and the cells formed by it are known as the *periderm*. The cells formed by the cork cambium toward the inside of the stem are parenchyma cells. As the cells formed toward the outside of the stem mature, they develop walls impregnated with *suberin*, a fatty substance impermeable to water, and become *cork*. All tissues outside of the corky layer of the periderm die because of lack of water (which ordinarily passes to them from the stele), and slough off, the cork functioning instead as the outer covering. Later new layers of cork cambium develop deeper in the cortex and even in the outer layers of the phloem. The tissues outside of these cork layers die and drop off in small bits, or in larger pieces or strips, as in the shagbark hickory and the sycamore, exposing the later formed cork layer beneath. The increase in diameter of the stem caused by the formation of secondary xylem and phloem splits the outer layers of the bark, which do not enlarge in circumference, producing the characteristic rough longitudinal furrows and facilitating the shedding of the dead portions. These changes explain why the phloem, though constantly added to from the inside, never gets much thicker, while the xylem increases in diameter each year. In time the bark of a stem or root comes to consist of only phloem and the tissues formed by the cork cambium. Cortex, epidermis, and much of the phloem

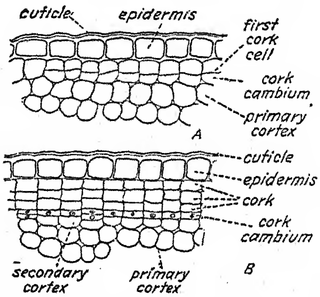


FIG. 102. Cross sections of portions of a stem showing origin of cork cambium (*A*), and the development of cork and secondary cortex from the cork cambium (*B*). (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

are killed by the formation of cork between them and the water supply, and slough off.

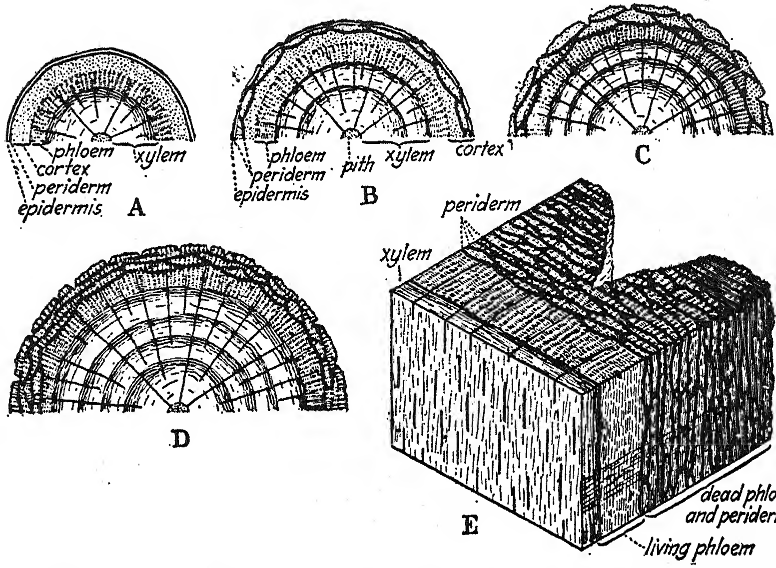


FIG. 103. Diagrams, based on *Quercus rubra*, showing the position and extent of successively formed periderm layers in a typical woody stem. *A*, one-year-old twig, the first periderm layer, a complete cylinder, formed beneath the epidermis. *B*, a two-year-old twig, the epidermis and first periderm ruptured; new, shell-shaped layers formed deeper in the cortex. *C*, a three-year-old stem, the outer tissues weathered away and more periderm layers formed still more deeply in the stem, invading the secondary phloem. *D*, a four-year-old stem, the cortex and outer secondary phloem weathered away with their periderm layers, the new cork layers invading the younger phloem. *E*, the outer tissues of an old tree trunk, showing the narrow band of young, living secondary phloem, and the thick, deeply fissured layer of older, dead phloem with its many shell-shaped periderm layers; a considerable amount of similar tissue has weathered away. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

80. Wounds.—The bark, composed of living cells and cork, forms a layer efficient in preventing the entrance into the wood of molds and related organisms which might cause it to decay. When a bit of the bark is knocked off or a branch is broken or cut, the wood is exposed. Such exposed wood may be covered eventually by a layer of new wood and new bark formed by the cambium at the edges of the wound. The readiness with which this covering forms is influenced by the shape of the wound and

FIG. 104. The trunk of a young pear tree, *Pyrus communis*, showing the cracking and scaling of the bark. The smooth, continuous outer periderm is cracking, and small, restricted inner periderm layers are beginning to form; two of these, just below the center of the figure, have "cut out" and killed patches of outer tissue. (From Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

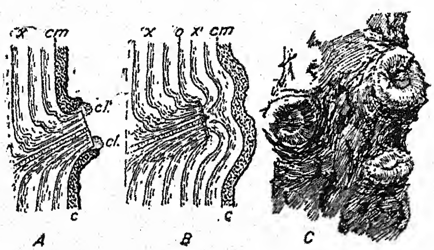


FIG. 105. Sections of a portion of a stem showing the healing of a wound caused by the cutting off of a lateral branch. *A*, formation of the callus, *cl*, owing to the renewed activity of the living cells exposed by the wound; *c*, cortex; *cm*, cambium; *x*, xylem. *B*, a similar stem three years later; *c*, cortex; *cm*, cambium; *x'*, xylem added since the wound was made; *o*, position of cambium at the time the branch was cut off; *x*, original xylem of the stem. *C*, trunk from which three branches have been removed, showing the gradual covering of the wounds by new tissue. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

by the closeness of the cut end of the branch to the surface of the main stem.

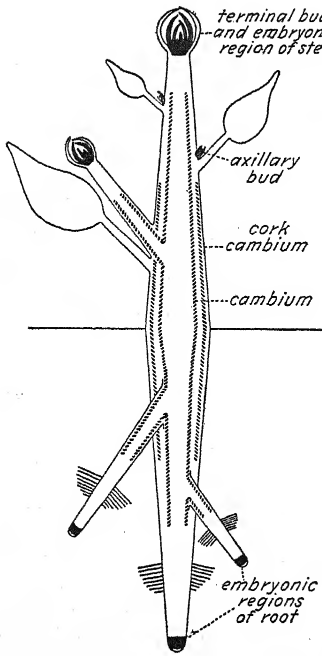


FIG. 106. Diagram of a dicotyledonous plant showing the embryonic regions in black and in dotted lines.

81. Lenticels.—At certain points (in the stem usually beneath the stomata in the epidermis) masses of parenchyma cells are formed by division. These enlarge, and split the corky layers outside them, forming places in the bark where the interior living cells are in free communication with the gases of the air. Such a spot in the bark is known as a *lenticel.* They are of many forms and sizes, each characteristic of the kind of plant. Their presence is a benefit to a stem or root in that it allows the entrance of oxygen which may be used in the respiration of the internal cells.

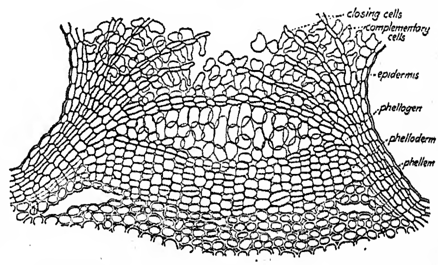


FIG. 107. Lenticel of *Prunus avium* (cherry) in transverse section of stem. A number of successive layers of complementary and closing tissue have been formed, and the large amount of phelloderm dips inward into the cortex. (After Devaux from Eames and MacDaniels, *Introduction to Plant Anatomy*, McGraw Hill Book Co., Inc., New York, N. Y.)

82. Growth of Monocotyledons.—In most Monocotyledons, such as corn and lilies, there is no secondary growth. There is no cambium in either root or stem; when the cells formed by primary growth have all ceased dividing and have enlarged and differentiated, growth in diameter ceases. Growth in length occurs at the stem tips and root tips as in Dicotyledons; and in addition certain cells at the nodes of the stem remain embryonic, and may elongate and differentiate later, long after the cells above and below have finished their growth.

83. **Factors Influencing Growth.**—The rapidity and total amount of growth depend upon a variety of external and internal factors. They depend, for example, upon the kind of plant. A variety of bamboo in the Philippines grows 82 feet in 90 days, while a red cedar does not grow so tall in as many years. Ordinary corn plants reach a maximum height of 6 or 8 feet. There are, however, dwarf varieties which never under the most favorable circumstances grow taller than a few inches. The rapidity of growth depends also upon the time of day, the time of year, and upon the age of the plant. Cell division frequently occurs most rapidly at night; trees and shrubs grow in length and diameter chiefly in the spring; annual plants, for example the sunflower, grow most rapidly while they are young and cease growth when they mature and form flowers and fruits. The speed and extent of growth are influenced by the supply of food materials, of water, of essential mineral salts, of nitrogen, and of gaseous oxygen, from which the body parts are constructed or which are concerned with the supply of active energy; and by the fundamental life processes, such as photosynthesis, absorption, respiration, digestion and translocation, which are concerned in the securing or utilization of these essential growth materials. Changes in temperature and in light and the presence of injurious chemical substances also may profoundly affect the rate of growth.

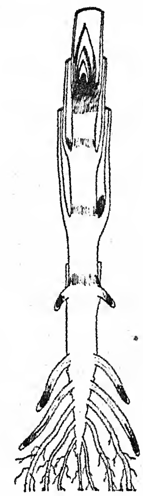


FIG. 108. Diagram of a longitudinal section of a monocotyledonous plant, corn, showing the embryonic regions in black. (Redrawn after Sachs.)

84. **The Complexity of Growth.**—This discussion of growth gives some slight idea of the immense complexity of the activities of a living organism—activities which we are accustomed to sum up carelessly in a word or two. In a growing plant cells are dividing at the tip of each branch of the stem, at the tip of each tiniest root, and (in a Dicotyledon) in the cambium cells through stem and root; cells are absorbing water, manufacturing new protoplasm and thicker cell walls, growing into all sorts of shapes in a definite and complex arrangement; water and foods and mineral matters are moving here and there through the stems and roots; leaves are spreading out, branch roots boring their way out through the

cortex, flowers and fruits appearing with the seasons; and we call it all by one name—Growth. Names are useful—but to name a thing is not to explain it.

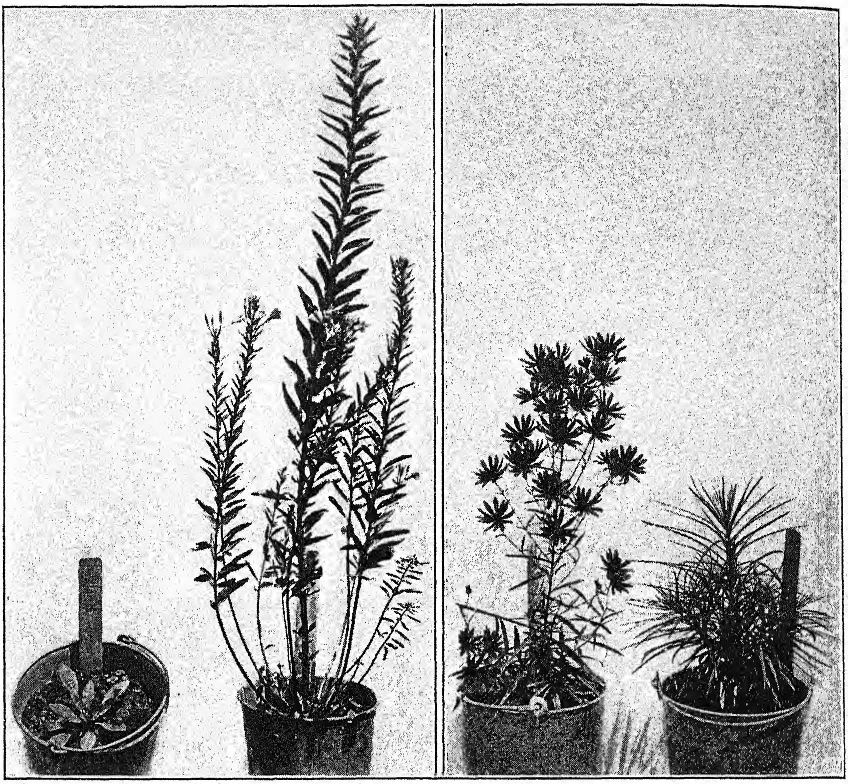


FIG. 109. The effect upon growth of the length of day. Left, evening primrose, *Oenothera biennis*, germinated in the fall, photographed July 17. Right, narrow-leaved sunflower, *Helianthus angustifolius*, germinated March 10, photographed July 31. From left to right the four plants were treated as follows: 8 hours of light from February 7 (short day); 10 to 15 hours of light (long day); 10 hours of light from June 10 (short day); 10 to 15 hours of light (long day). The primrose flowers in the long day, the sunflower in the short day. (Courtesy of W. W. Garner and the United States Department of Agriculture.)

CHAPTER X

Reactions of Plants

85. Reaction to Light.—Everyone has noticed that plants grown indoors near a window turn toward the light. This fact may be tested experimentally by placing a growing plant in a box to which light is admitted only through a small hole in one side. The stem, instead of growing upwards as usual, will turn and grow toward the hole through which light enters, and, if left there long enough, will perhaps grow out through the hole.

Evidently light affects the growth of the plant in some way. A curvature in growth is brought about by the cells on one side of the stem elongating more rapidly than those on the other side. In the experiment just described, the cells farthest away from the light grow the fastest, causing the stem to turn toward the light. When a plant is growing outdoors, and not heavily shaded on one side, all sides of the stem are about evenly illuminated; and the direction of growth is more or less upright.

Fig. 110. A plant of *Bryophyllum calycinum*, showing adjustment of leaves in response to light. Light from the left.

Many plants (for instance bean plants), in addition to growing toward the light, possess the power of slowly moving their leaves until their blades are perpendicular to the direction of the light. Other plants place their blades parallel to the sun's rays, presenting the edges of the leaves. The flower head of the sunflower turns so as to face the direction of the sun's rays.

Such results may be obtained, of course, not only by changing the direction of the light, but also by changing the plant—for instance by turning it around—so that light reaches it from a new angle. What has been said of light applies also, as we shall see, to other forces and to various substances with which the

plant comes in contact; when such forces or substances are changed (or when the plant's relation to them is changed), there is a change in the activities of the plant—in growth or in some other activity. The forces and substances with which the plant is in contact make up what we name the environment of the plant. Changes in the environment, such as changes in the direction of light, which cause a change in the plant, are known as *stimuli* (singular, *stimulus*); and the changes within the plant are known as *responses* to the stimuli.

There are many things yet to be explained in the responses to light stimuli. Why do cells elongate more rapidly when poorly lighted? We know that this is so, in many plants, and we can name the fact a response to light stimuli—but we cannot yet explain the processes, the mechanisms, which bring about the results. It does not seem to be connected with the food supply. The region of elongation—where such responses occur—is often not green and cannot carry on photosynthesis. And the cells of a plant in the dark have usually an abundance of food, and therefore energy, for at least a time. Light, in causing these responses, is evidently acting in a manner quite different from any we have so far studied.

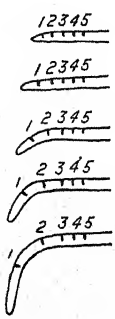


FIG. 111. Response to gravity of corn root.

The response is not the same in all kinds of plants, nor even in all parts of the same plant. Some plants turn their stems, some their leaves, some both, toward the light. In many plants only the main stem responds positively to light by growing towards it; the branches grow *across* the path of the light, or, as we say, respond transversely. And some stems, such as many vines, grow clinging to other objects without any apparent reference to the direction of light.

86. Reaction to Gravity.—Another force in the environment, a change in which is a stimulus, is gravity. If a plant is laid upon its side in a totally dark box (so as to exclude light stimuli and their responses), the stem turns and grows upwards—in a direction contrary to the pull of gravity. The treatment is, of course, equivalent to changing the direction of gravity—since the latter is now acting upon the plant from a different direction. The same thing may be observed in the germination of seeds. The farmer

does not place each grain of corn so that the tiny root points down and the tiny stem points up; but the root turns and grows down, the stem turns and grows up, no matter in what position the kernel

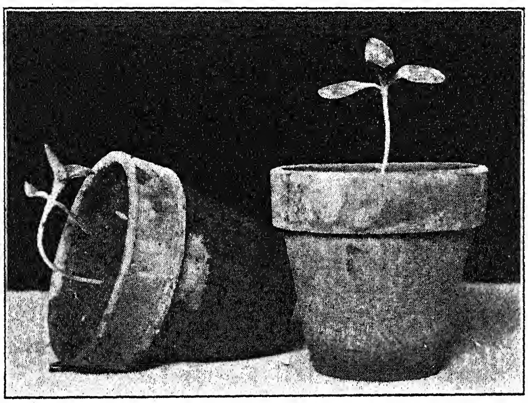


FIG. 112. Response to gravity of sunflower seedling.

is placed. This may be easily illustrated by a laboratory experiment. If kernels of corn (or other seeds), germinated, with the young root protruding, are pinned in various positions to a piece of cork, and placed in moist sawdust (so that light is excluded and moisture is equally present on all sides of the kernel), and examined after a day or two, it is found that the first roots of all the kernels are growing down—no matter in which direction they were pointing at the beginning of the experiment—while the stem with its leaves is growing up.

Since we have excluded all other stimuli that we know of, we must conclude that in some way the force of gravity has caused these changes in direction. The same thing is shown by experiments which subject a plant to a force of the same nature as gravity

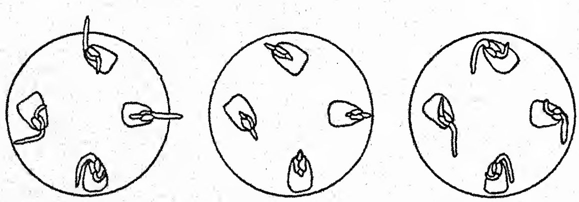


FIG. 113. The effect of centrifugal force on the reactions of root and stem. Middle, condition at the start; right, wheel at rest; left, wheel rotated rapidly.

and stronger than it—namely, centrifugal force. If seedlings are placed on a rapidly revolving horizontal wheel, their roots grow out from the circumference (*with* the centrifugal force), and their stems in toward the center (*against* the centrifugal force). In this experiment the centrifugal force is greater than the force of gravity, and the roots respond to it instead of to the force of gravity. Another sort of experiment practically removes the force of gravity. It consists in placing seedlings on a *vertical* wheel revolving *slowly*. Before gravity can affect the growth of a root or stem in any one direction, the revolution of the wheel has changed the plant's

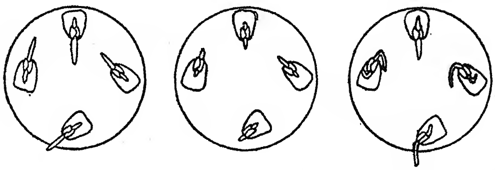


FIG. 114. The effect on the reactions of root and stem of the elimination of gravity. Middle, conditon at start; right, wheel at rest; left, wheel rotated slowly, completing a revolution in 20 minutes.

relation to gravity—turned the plant the other way up. It is as if gravity were pulling equally from all directions at once. Under such conditions neither root nor stem responds to gravity; each continues to grow in the direction in which it happened to be pointing when placed on the wheel.

It may seem strange, at first thought, that the same force (which we ordinarily think of as only making things go down, or "fall") can at the same time cause the root to grow down and the stem to grow up. But we must make a distinction between the *force* of gravity itself, which tends to pull a body down if that body has sufficient mass, and the *response* to gravity, a reaction or series of reactions in the protoplasm, which causes certain cells to elongate more rapidly than others. The root is not pulled, does not fall, down through the soil. If one cuts off a root and lays it on soil, it will not disappear beneath the surface—it has not sufficient mass to overcome the resistance of the soil. It is the influence of gravity upon those reactions which we call growth which sends it down. Now we know that there are many differences between root cells and stem cells; and it is not hard to realize that it is possible for root protoplasm to react in one way to gravity and

stem protoplasm in another—just as different sorts of stems and leaves react differently to light.

As with the response to light stimuli, the exact mechanism of the reactions to gravity is not understood. It has been proven, however, that the root cap plays a necessary part in the response, although it is the elongation region that actually does the bending (bending here, as in the response of a stem to light, is caused by more rapid elongation of cells on one side of the root than of those on the other side).

87. Other Tropisms.—There are still other forces, and many substances, in the environment that influence the direction of growth of plants. The presence of water in different amounts on different sides of a plant often influences the direction of growth of roots. Such turnings as a plant makes in response to such stimuli are known as *tropisms.* The property of turning toward light is known as *Phototropism;*[1] reactions to gravity are instances of *Geotropism;* reactions to chemical substances are classed under *Chemotropism;* and so forth. The response may be, as we have seen, *positive*, *negative*, or *transverse*, according as the plant grows toward, away from, or across the direction of the force or substance which is acting as a stimulus. A stem may be positively phototropic and negatively geotropic. The tropisms are also spoken of as instances of the *directive influence* of light, gravity, and so forth, since they concern the direction of growth.

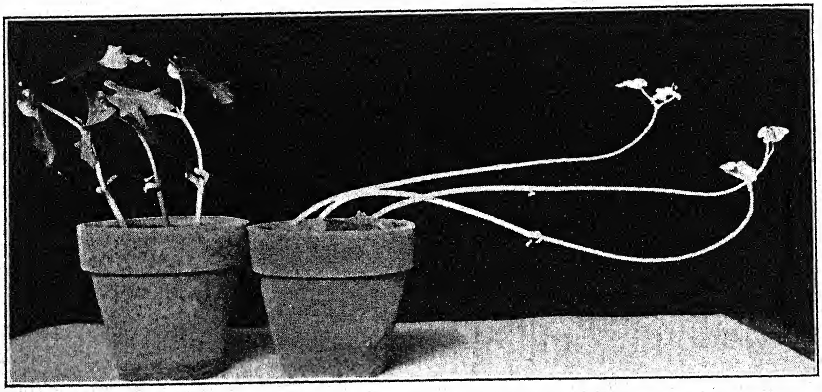


FIG. 115. Formative influence of light. Bean (*Phaseolus*) grown ten days in light (left) and ten days in dark (right).

[1] Or *Heliotropism.*

88. Formative Influence of Light.—Plants may respond to stimuli in other ways than by tropisms. If the light which a plant receives is much reduced or entirely cut off, the result is an elongated plant devoid of chlorophyll and lacking in rigidity—a long, straggling, weak, white or yellow object, living upon stored food and manufacturing none. The part played by light in the determination of the form and color of the plant is known as the *formative* influence

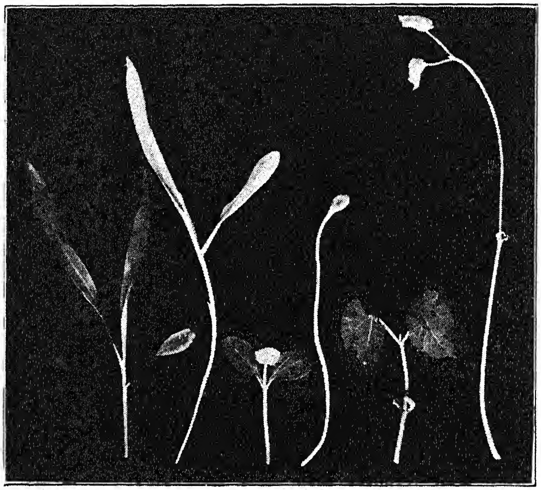


FIG. 116. Formative influence of light. Plants ten days old. From left to right: corn in light, corn in dark; squash in light, squash in dark; bean in light, bean in dark.

of light. Various chemical substances, and other stimuli, also have a formative influence on plants.

89. Temperature and Reaction.—The processes that occur in a living plant are, as far as we understand them, chemical and physical processes; and these are often markedly influenced by the surrounding temperature. It is not surprising, therefore, that changes in temperature often act as stimuli and cause changes of reaction—responses—in the plant. This is well illustrated in the streaming of the cytoplasm in such a cell as that of *Elodea*—a process which can be watched under the microscope. If the temperature of the water in which an *Elodea* leaf is placed is raised above room temperature, the streaming becomes more rapid; at a temperature of approximately 35°C. the streaming is most rapid;

at still higher temperatures it becomes slower; and finally at about 50°C. it ceases. Similarly if we cool the leaf, streaming becomes slower and slower and finally ceases. There is one temperature at which streaming is most rapid, and both higher and lower temperatures cause a decrease in the rate of movement; there are

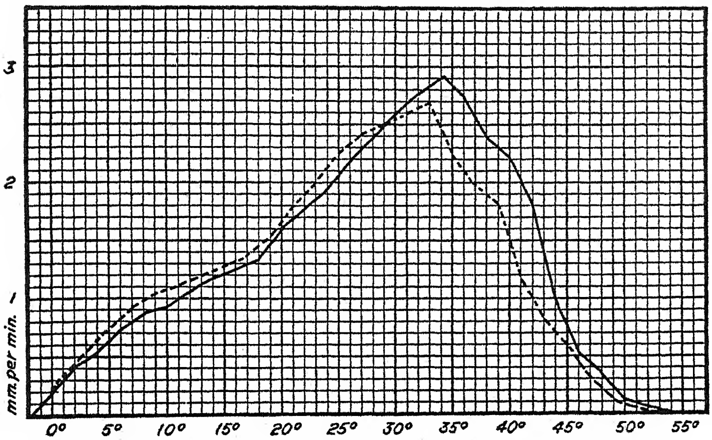


FIG. 117. Graph (curve) showing the effect of temperature upon the rate of protoplasmic streaming in *Nitella.* Continuous line is average result, broken line a single determination. (From Ganong, *Plant Physiology*, Henry Holt & Co.)

certain high and low temperatures at which streaming stops altogether.[2] Many other life processes behave in a similar manner.

90. Plant and Animal Reaction.—What we have said of plants applies also to animals; in fact, it is very much more evident. When a child puts a finger on a hot stove, he almost instantly and very rapidly withdraws it—perhaps even before he has had time to think about it. A considerable response may be obtained also by sticking a pin into him—a response which may involve movements of limbs, contortion of facial muscles, emission of noise, and other things. The contact with the hot stove or the pin point are changes in the environment of the child, and consequently produce changes in the reactions taking place within him. Animals, in fact, respond usually much more quickly and vigorously than

[2] The conditions which produce the most rapid response are called the *optimum* for that response; the upper and lower limits are called the *maximum* and *minimum* respectively.

do plants[3]—largely because of their possession of nerves and muscles. Actual movement, of parts or of the whole organism, is a common characteristic of animal responses, while it is comparatively rare and slight in plants.

91. **Reactions of Mimosa.**—There are a few plants, however, that behave toward stimuli almost as an animal behaves. One of these is the so-called sensitive plant (*Mimosa pudica*). The leaf

FIG. 118. Reaction of *Mimosa pudica* to a stimulus. The leaf at the right has been stimulated. (From Pfeffer, *Plant Physiology*, Clarendon Press, Oxford.)

of this plant is divided into four main parts, called *pinnae* (singular, *pinna*), all attached at the same point to the petiole; and each of these parts is in turn divided into a large number of very small parts, called *pinnules*. If the tip of a pinnule is gently touched,

[3] A corn root must be exposed to the stimulus of gravity for from 20 to 30 minutes before it will respond to gravity and the response will not be evident until 3 or 4 hours after the exposure. We might say then that the time required for the corn root tip to "perceive" the stimulus of gravity is 20–30 minutes and the reaction time is 3–4 hours.

it almost immediately moves upwards on the axis to which it is attached; usually the pinnule opposite also moves up, so that the pair of them stand close together, or folded up, instead of spread apart. If the touch is sufficiently strong, the next pair of pinnules may similarly close up, and, a moment later, the next pair, and so on. If the tip of the leaf is burned or cut, all the pinnules on the pinna may close up successively; more than that, the whole pinna may droop on the petiole; and, at the same time, the mysterious reaction may proceed up the other pinnae and *their* pinnules progressively fold together, from the base of the pinna outwards; a little later the whole leaf may droop, the movement occurring at the base of the petiole; and the reaction may even extend up and down the stem to other leaves, which are similarly affected.

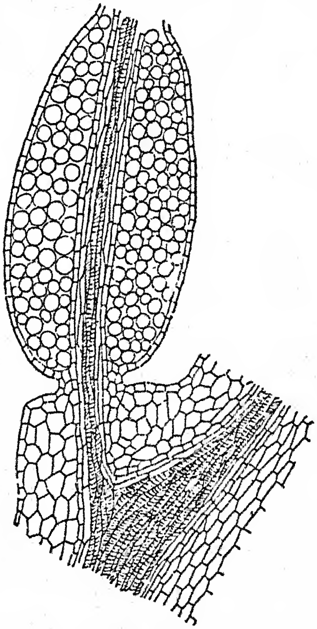


FIG. 119. Diagram of a lengthwise section of a pulvinus of *Mimosa*. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

In several ways this response resembles those of animals. There is an evident transmission of the stimulus from the place where it is applied to other parts of the organism. The reaction occurs rapidly, so that visible movement results. And the response is affected by definite motor organs. When the eye receives a stimulus in the form of a picture of an automobile charging violently towards the eye's owner, certain muscles in the body and legs operate to put that person beyond danger; obviously something traveled from the eye to those muscles. In *Mimosa* a "something" must also travel from the point where a touch or injury is applied down the axis of the pinna, down the petiole, and into the stem—the distance it travels depending upon the violence of the stimulus. The visible response is effected by certain small organs known as *pulvini* (singular, *pulvinus*) at the bases of the pinnae, of

the pinnules, and of the whole leaf—that is, in every place where movement takes place. Just as in an animal the eye perceives the stimulus, the nerves transmit it, and the muscles effect a response; so the end of the leaf (though not possessing a specialized sensory organ) receives the stimulus, the cells of the leaf and petiole (though not specialized into nerves) transmit it, and the pulvinus brings about the visible response. The response is due to the excretion of water into intercellular spaces by the cells on one side of the pulvinus, with a consequent shrinkage of those cells. After a time, if undisturbed, these cells reabsorb the water, increase in size, and move the parts of the leaf back to their normal positions. If an animal is subjected to the vapor of ether, it loses the power to perceive and respond to stimuli of various sorts—becomes, as we say, unconscious. This is true also of *Mimosa*. If it is subjected to ether, it may be touched, cut or burned without any visible response.

92. **Sleep Movements.**—Darkness is one of the stimuli to which *Mimosa* responds by folding its pinnules and drooping its pinnae and entire leaves. This fact is also true of some other plants, such as clover and *Oxalis*. These plants change the positions of the parts of their leaves during darkness—a process spoken of as "sleep movements," though not comparable to animal sleep.

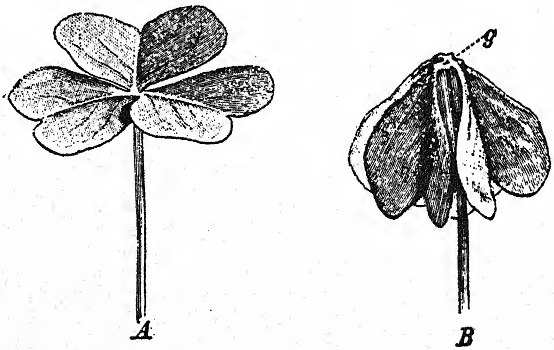


FIG. 120. "Sleep movements" of leaflets of *Oxalis acetosella*. *A*, Leaflets expanded; *B*, after a period in darkness. The pulvini are at *g*. (From Pfeffer, *Plant Physiology*, Clarendon Press, Oxford.)

When the light returns, the leaves resume their extended positions. Flowers also exhibit movements in response to light, opening at various times during the day or night. The flower heads of dande-

lion close during the night and reopen in the morning; the night-blooming *Cereus* opens at night. Changes of temperature also influence the movements of flower parts of some common plants, such as the tulip and star-of-Bethlehem.

93. **Other Stimuli and Reactions.**—The capacity to respond to stimuli is common to all living plants and to all living animals; the nature of the responses, even to similar stimuli, varies greatly in different kinds of organisms. This power of living things to react is often discussed under the term Irritability. The word is obviously borrowed from animal behavior; to speak of a plant as irritable strains the ordinary associations of the word considerably. The reactions which have been described in this chapter are obvious reactions to particular stimuli. Even an untrained observer can note these responses and trace the connection of the stimuli with them. Because of their obviousness there is a tendency to consider these types of reactions as the only ones evidenced by living things. Yet it is clear that changes in the water supply or in the type and quantity of mineral nutrients constitute stimuli also to which living organisms respond. In fact all organisms spend all their lives exposed to the influence of various sorts of forces, such as light and gravity; and of various substances, such as food and water; and as these forces and substances are never constant in amount and direction for very long they constitute stimuli to which organisms may respond. All organisms spend all their lives responding to stimuli of one sort or another. This is perfectly evident when we reflect that life is dependent upon the continual occurrence of many processes within the organism, such as that of respiration (directly respiration stops, life stops); and that all such life processes about which we know anything depend upon substances received from the environment or upon energy entering from the environment. Respiration, for instance, is usually a reaction between oxygen—from the environment—and food—composed of materials derived from the environment and put together by protoplasm with the help of energy from the environment. Cell enlargement, again, is the result of water in the environment coming in contact with living cells; or of food entering cells; or of both. It is true that we do not yet know the exact substances or forces concerned in all activities—we do not know the causes of mitosis or of differentiation; but food and other chemical substances are almost certainly involved in both these; and since all the activities of

which we do understand anything are reactions between organism and environment, we assume that all other activities are also. In fact, it is difficult to imagine any life process entirely independent of the substances and forces surrounding the organism. At the bottom of all our *living* are our "three meals a day"—substances which must be taken in if life is to continue; and they are stimuli just as much as is a pin prick or a blow.

It follows, of course, that if the substances or forces outside the organism are changed, or if their relation to the organism is changed, the activities of the organism which involve such forces and substances will also change; this is the real meaning of stimulus and response. Reactions are going on all the time—the *activities of a living thing are reactions;* responses to stimuli are simply *changes in reactions.* The so-called Irritability is not a process of living matter, like respiration or photosynthesis, but is a feature which is common to all life processes that we know, and hence a term almost synonymous with life itself.

94. **Teleology.**—It is a noteworthy characteristic of many responses to stimuli, especially the tropisms, that they are of such a nature as to enable the processes of the plant to continue, and therefore to insure the continuance of life. For instance, if a plant starts its life overshadowed by a rock or building, it is in a place which will not permit photosynthesis to go on very rapidly; since the light intensity is low, the amount of food manufactured will be small, and the plant will not be highly successful. But because of its phototropic properties, the plant turns toward the light as it grows, and very probably its tip will emerge into a better lighted area, and it will be consequently more successful. Similarly with the response to gravity. The stem being negatively geotropic grows up and out of the soil into the light, where it can manufacture food; while the root, being positively geotropic, grows down into the soil and thereby comes in contact with abundant water (which is usually present at some distance below the surface). It is easy to imagine what the results to the plant would be if the root grew up into the air and the stem down into the soil.

Now, as we said previously, we know very little of the mechanism of these tropisms; we do not know *how* gravity causes certain cells to elongate more rapidly than others. We do know, of course, why there are no plants responding in unfavorable ways; if there ever were such, they died. A very simple explanation of the fact

that plants do respond as they do, however, is to be found in many unscientific books and in the minds of persons not trained in science. It consists in the statement that plants respond as they do because they *have to;* if they did not they would die. Or, putting it in a slightly different form, they respond as they do *in order to* continue to live. Thus it might be said "a plant shoot grows upwards from the seed *in order to* obtain light for the manufacture of food."

Such a statement implies that the plants have consciousness, that they know what they are doing, that they know that they must have light in order to live, and therefore set about reaching it. This is the way in which many animals operate—including ourselves. When we are hungry, we know of several things that will cure that condition, and we set about obtaining some of them. Now it is known that animals do these things by means of brains, nerves, and so forth; and *no such organs have ever been found in a plant*—in fact, no organ at all which we have any reason to believe can think or reason about things. Therefore when we make such a statement as the one quoted above, we are speaking as if we knew certain facts that we actually do not know—and such ways of speaking and of thinking are unscientific, for science is based only upon observed facts.

Furthermore, when we say "a plant forms stems and leaves *in order to* manufacture food," we are crediting the plant not only with the possession of the power of reason, but also with the power to change its own functions at will; and this is a thing which is limited even in human beings. How many people would maintain that a man, even though possessed of a brain, could so change his structures and functions that he could live, like a fish, under water? The man might very well know, if immersed suddenly in the ocean, what was necessary for him to make this change in his ways of life—among other things, gills instead of lungs; but he could not provide the gills. Yet plants have been said to have provided themselves with xylem vessels in order that their leaves may have water, to have developed seeds with wing-like expansions in order that they might be transported to places favorable for their growth, and to have accomplished many similar miracles. The authors of such statements are called *Teleologists*.[4] Teleology is a very human point of view. *We* do many things with purpose; and we assume that the things which a plant or animal does are also

[4] Teleology is speaking of goals or purposes.

caused by purposes. Scientifically, we must learn to look on such things as the *results of causes*—whether or not we know the causes. We should not dream of saying that a certain mountain exists and has a hole in its peak *in order that* there may be volcanic eruptions from it. We are able to be quite scientific in speaking of the mountain, and say that *because* the mountain and the earth beneath have such-and-such a structure, there are eruptions. We must be equally scientific in considering plants and animals.

We must not forget, also, that many responses are far from beneficial. Wilting may be a response to a lowering of the water supply. Death itself is a response to stimuli. The teleologist, to be consistent, should say that a plant absorbs a poisonous mineral from the soil in order that it may die!

However, it must be emphasized that science cannot *deny the possibility* that plants have wills and purposes, and that they govern its life, or that there is some all-knowing Power directing their activities. Teleology may represent, for all we know, the truth; but it is unscientific nevertheless, because it assumes things for which there is as yet no evidence in the sense of observable or demonstrable facts. Therefore we must avoid it in Biology—the *scientific* consideration of life. We must give as reasons for structures and functions only known causes; and we must be prepared, when we cannot find the cause, frankly to admit our ignorance—and to go on looking for one.

CHAPTER XI

Life and Death

We all know or think we know what life is; and we all have come close enough to death to think we know what that is. Yet when we try to state the exact difference or differences between a living and a non-living body we find it a surprisingly difficult matter. Most of us think of a living thing as one which is capable of movement and responds to stimuli.

95. **Life and Movement or Response to Stimuli.**—If we place a globule of mercury in a dilute solution of sulfuric acid containing some potassium dichromate, and touch the mercury with an iron wire, it will contract; if we remove the wire, it will again expand. If we place the wire so that it just touches the edge of the expanded globule of mercury, it will contract and expand rhythmically and so imitate the regularity of the beat of a heart. Here, then, is something which moves and which responds to a stimulus, two things which we are most likely to associate with living things, and yet which we all agree is not alive. We can therefore use neither movement nor responses to stimuli as criteria for certainly separating the animate from the inanimate.

96. **Life and Growth.**—But although the drop of mercury moves and responds to stimuli it does not grow. Perhaps growth is a surer standard for the living condition.

If we place a crystal of potassium ferrocyanide, a yellow semi-transparent chemical substance, in a tube containing dilute copper sulfate, a light brown, elongated structure covered with bumps and protuberances develops in the course of a few minutes. This (called the Traube cell) enlarges in size, forms short appendages; in short, grows. This structure which forms in the tube consists of a sac of a reddish brown material, copper ferrocyanide, formed by the reaction of the potassium ferrocyanide and the copper salt. The interior of the sac is filled with a solution of the potassium ferrocyanide. Because of the continued solution of the crystal of potassium ferrocyanide, the solution inside of the sac contains a concentration of dissolved material greater than is present in the dilute copper sulfate outside. The copper ferrocyanide is an

excellent semi-permeable membrane and therefore all the conditions for the osmosis of water and for the development of osmotic pressure are present. Water osmoses into the sac and the pressure which develops causes the sac to swell. When the pressure ruptures it the potassium ferrocyanide flowing out meets the copper sulfate, reacts with it, forming copper ferrocyanide, and thus repairs the break. Anyone would have trouble in convincing you that this sac is alive, in spite of the fact that it grows, in spite of the fact that it is built of a brown material, copper ferrocyanide, different in appearance and different in chemical composition from the two substances with which we start, and in spite of the fact that it repairs itself as described above.

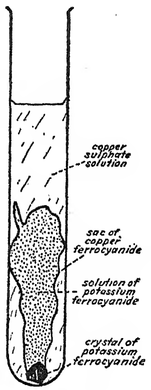


FIG. 121. Diagram of Traube cell.

97. **Life and Other Characteristics.**—You may say, however, that the sac cannot reproduce. That is true, and reproduction is a characteristic we frequently associate with life. But there are living things, such as the mule, which are sterile. You may say that the sac is not composed of organic substances such as are found in living organisms. It was once considered that the formation of compounds containing carbon distinguished things which were alive from those which were not. In fact this group of chemical materials was called organic because of the belief that the substances belonging to it could be derived only from organisms. But in 1828 the German chemist, F. Wöhler, synthesized artificially an organic compound, urea, from inorganic materials; and now the chemist can make in the laboratory many of the organic compounds which we find in living things. You may suggest that in the growth of this sac there is no digestion of food, and no decomposition of food materials with the resulting supply of energy for heat and work, and that here we have a set of phenomena which are peculiar to living things. The digestion of food and the utilization of the food for building the body parts and for furnishing energy for heat and work include a set of phenomena which has been considered peculiar to living things. But we know that starch can be digested by sulfuric acid and heat. We know that sugar and alcohol can be burned and the stored energy they contain transformed into heat and light. It is true that in the living

organism no temperatures exist such as are necessary to burn sugar on a stove or alcohol in a lamp; and we know that from sugar or from alcohol living organisms can secure energy in the form of heat and energy for doing work. This might suggest that there are, in living organisms, processes, chemical reactions, by which foods are used, which cannot be imitated or duplicated outside of the living organism itself. The discovery of enzymes, however, has enabled us to duplicate in a test tube many of the changes involved in assimilation and dissimilation in the living organism. This leads us to believe that probably all the processes of assimilation and dissimilation take place according to known or discoverable laws of chemistry and physics and that none of them are necessarily peculiar to life. We simply do not yet know enough to tell just how or to imitate exactly all of the steps by which material is incorporated into the bodies of living things.

98. **Distinction between the Living and Non-living.**—And so it goes with other characteristics which have been selected for the purpose of differentiating the living from the non-living. We find either living things which do not possess them or analogies in non-living things which make it impossible to use them as a standard for distinguishing living things. We have been unable thus far to select any one thing which characterizes living things, which differentiates them entirely and distinctly from the non-living. It is a combination of characteristics, chief among which are the dynamic character of living things and their self-running and self-perpetuating nature, which we commonly use in differentiating living organisms from other things. We may describe a living thing, awkwardly and incompletely, as a thing which is capable of movement, responds to stimuli, is capable or has been capable of growth, has or has had the power of reproduction, builds its body of substances different from those which compose its body structure, and makes its own repairs; if we are acquainted with biological facts we also think of living things as composed chiefly of water and organic substances, constructed of one or more units called cells, and in our experience derivable only from previously existing living bodies. Living things are dynamic, by which we mean continually changing, while many (though not all) non-living things are static, that is, comparatively changeless. Compare the active life of a man with the inert existence of a stone.

The importance of the difficulty in separating the living from

the non-living is evident at once. It suggests to us the possibility that living things are not different in kind from non-living things but are different only in degree; that there is nothing peculiar to living things, nothing with which we may not become acquainted outside of the organism. It suggests to us that the sensitiveness of living things to stimuli and their reactions to them are due to the same causes as the sensitiveness of non-living things and their reactions to changes in environmental stimuli; the difference between the two classes being only that the things which are alive usually respond more vigorously to smaller stimuli.

While the characteristics summarized above may enable us to separate most living things from those which are not alive, they do not tell us what is responsible for the living condition, what causes the reactions of life to be so much more complex and numerous than those in non-living things. We know that we must look for the answer to this question in the protoplasm of the cell, but this merely locates the problem in a specific place and does not solve it.

99. **Explanations for the Living Condition.**—The oldest and probably the commonest explanation is that there is present in living organisms an essence, or spirit, or vital force, which is different from the forces which we know outside of living things. According to this idea death occurs when the vital force leaves the organism. There are many questions which are difficult to answer on this basis. Is there one vital force for an entire individual organism or does each cell have its own? What happens to the vital force when an individual is cut into pieces and each remains alive? It is possible that answers to these questions and others like them might be found, but there is still the very great difficulty that the assumed vital force is something which cannot be studied or worked with separately from living organisms. You might very well suggest that it be studied in the living organism if it cannot be studied apart from it. But how are we to determine whether the particular phenomenon we observe is due to the vital force or due to some forces or occurrences with which we are acquainted or can become acquainted outside of the organism? For example, it was considered that the digestion of starch was due to this vital force, until the enzyme diastase was discovered.

In order to avoid similar errors we must try to account for the various activities and structures of living organisms on the basis

of what we know occurs outside of the living body (by the laws of physics and chemistry). There may always be a residuum which cannot be accounted for by known or discoverable laws of physics and chemistry, and which would therefore be due to a vital force. The scientist is not now and may never be in a position to deny the possibility of the presence of a vital force in living things.[1] But to avoid assigning to a supposed vital force powers which it does not have the scientist must assume for his working plan that life can be accounted for by known or discoverable laws of chemistry and physics. This idea is sometimes called the mechanistic conception of life.

100. **Vitalistic Conception.**—The vitalist assumes that any particular process at present known only in living things (for example mitosis) owes its existence to the direction of the vital force. This means of course that we cannot study it, at least by ordinary means, since the vital force is by definition quite different from all the forces and substances with which we know how to work and experiment. When we say, for instance, that mitosis is due to the vital force, we are merely covering with a name our ignorance of the causes of it, and placing the process in a class of things which we cannot investigate by any known method; it amounts to giving up the problem. As a matter of fact, the vitalistic attitude has never led to any great advances in biological learning.

101. **Mechanistic Conception.**—The mechanist, on the other hand, assumes that mitosis and respiration (for example) are complex examples of the workings of the same physical and chemical laws which we already know, or with which we can become ac-

[1] Professor D'Arcy W. Thompson in his Presidential address in 1911 before the Zoölogical Section of the British Association for the Advancement of Science put this as follows:

"While we keep an open mind on this question of vitalism, or while we lean, as so many of us now do, or even cling with a great yearning, to the belief that something other than the physical forces animates the dust of which we are made, it is rather the business of the philosopher than of the biologist, or of the biologist only when he has served his humble and severe apprenticeship to philosophy, to deal with the ultimate problem. It is the plain bounden duty of the biologist to pursue his course unprejudiced by vitalistic hypotheses, along the road of observation and experiment, according to the accepted discipline of the natural and physical sciences. . . . It is an elementary scientific duty, it is a rule that Kant himself laid down, that we should explain, just as far as we possibly can, all that is capable of such explanation, in the light of the properties of matter and of the forms of energy with which we are already acquainted."

quainted, outside of living things. Consequently they can be investigated, and, ultimately, explained in the same way as non-living activities (behavior of falling bodies, diffusion of gases, etc.) have been investigated and explained. Perhaps this is an unwarranted assumption. But it has resulted in all our great advances in biological knowledge, knowledge which has proved of immense importance and benefit to mankind. The discovery of enzymes has already been given as an example. Mechanism may not be the final truth about life; but it is a useful point of view; it "works."

102. Mechanistic Theories.—The mechanist is not yet in a position to answer completely the question concerning the causes of the living state. Various theories have been advocated which seek to answer the question in the terms of physics and chemistry.

It has been suggested that the protoplasm is alive because it possesses unusual or peculiar chemical compounds; and that death is due to the change in character of these compounds. It has been suggested that the protoplasm is alive not because it possesses unusual chemical compounds but because of the way in which these compounds are arranged; just as a watch runs not because it is made of wheels and springs but because of the way in which the wheels and springs are arranged. It has also been proposed that the protoplasm is merely the substrate in which a particular series of chemical reactions occurs and that the occurrence of these reactions is responsible for living characteristics. Life thus conceived is analogous to a gas flame, which owes its existence to the oxidation of the particles of gas; when the oxidation reactions cease the flame goes out. There is evidence for each of these ideas. When a living thing dies we can observe changes, for example coagulation or liquefaction, in the character of the protoplasm; we can observe changes in the rates of certain chemical reactions; we can observe changes in water-absorptive capacity and the capacity to absorb dissolved materials. There are also objections. Perhaps a combination of these ideas more closely fits the facts than any single one.

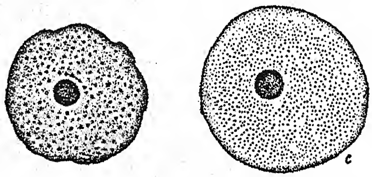


FIG. 122. Visible change associated with death. Right, living nucleus from a cell of *Elodea;* left, the same nucleus after the cell has been killed with alcohol.

103. Scientific Conception of Life.—Most biologists consider a

living thing to be alive and to grow, to do and be what it is because its protoplasm is made of particular chemical compounds, which are arranged or organized in a particular way and carry on a particular series of physical processes and chemical reactions. A small change in the character of the chemical compounds or in their arrangement or in the series of physical processes and chemical reactions results in the organism being abnormal in action or appearance; and a sufficient change in any one of the three results in death. This point of view may be made clear by an analogy.

If a small cone of mercury sulfocyanate is lit at the tip, the burning compound forms a long serpent-like ash a hundred times or more the volume of the original cone. This is the familiar firework called Pharaoh's serpent. The growth of Pharaoh's serpent depends upon the particular kind of material of which the cone is made. A cone of charcoal, sulfur or gun-powder will not do. It must be mercury sulfocyanate. It also depends upon the way

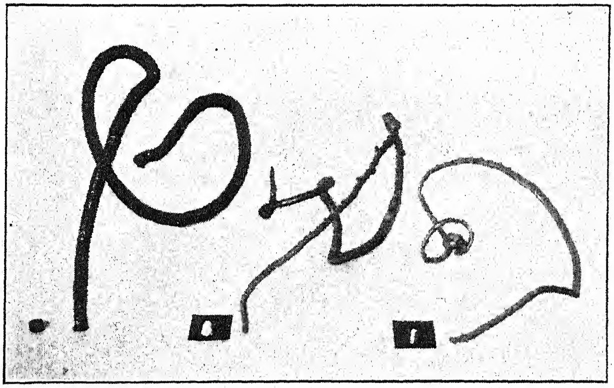


FIG. 123. Pharaoh's serpents. The material from which each "serpent" grew is shown at its left.

in which the mercury sulfocyanate is arranged. A cone yields one sort of serpent—a cylindrical pill one somewhat different. The development of the serpent depends also upon the chemical reactions which the stuff carries on. Only burning (oxidation) will form a snake. Other types of reactions such as reduction or combinations with compounds other than oxygen will not produce the same result. Even though a cone made of mercury sulfocyanate is used a serpent will not be formed unless the cone burns from the tip.

It must not burn at the same rate on all its surface or some other kind of monster will grow out of it. This means that certain physical conditions also must be met.

So the scientist pictures living things as essentially particular types of chemical compounds, organized or arranged in particular ways and carrying on certain physical processes and chemical reactions. This has been found to be a useful way of considering living things. It is not necessarily a complete explanation of the phenomena of life.

104. **Limitations of Science.**—Here it is perhaps worth while to ask the question: May there not be things in the universe which science cannot, by its very nature, even investigate, far less make plain? Science can "explain" a thing by showing how it is related to other things already known; it can perhaps "explain life" by interpreting life as the results of physical and chemical laws; but upon what basis can it "explain" these laws? If everything has a cause (as science assumes), can we know—or even imagine—the first cause of everything? Chemistry has discovered that matter is composed of molecules, molecules of atoms, atoms of electrons—of what are electrons composed? We are told that we are surrounded by infinite space—can we picture infinity in our minds? Or, on the other hand, if we say that space is finite, has a definite boundary—then what is beyond that boundary? We are equally unable to picture that. We cannot therefore image or understand, by our mental processes, the final truth about the constitution of matter, about space, about the universe. We can merely seek to relate to each other the known, understandable *facts* which we can observe; and that is what we call Science. We may *also* believe in supernatural forces or persons, the spirit or essence of life, or anything of that kind; but we cannot prove them by observed fact. Neither can science disprove them, since by definition it cannot deal with such matters: they are outside its province. This limitation of science does not destroy its usefulness, since a clear understanding of cause and effect, even though we do not know the ultimate cause, has freed us from superstition, and has given us the comforts and conveniences of our present civilization.

Science cannot deny the existence of things. We no longer believe in winged horses or water babies; but it is difficult to base our disbelief on scientific reasoning, as is demonstrated in the following delightful extract from Kingsley's "Water Babies."

"'But there are no such things as water babies.' How do you know that? Have you been there to see? And if you had been there to see, and had seen none, that would not prove that there were none. If Mr. Garth does not find a fox in Eversley Wood—as folk sometimes fear he never will—that does not prove that there are no such things as foxes. And as is Eversley Wood to all the woods in England, so are the waters we know to all the waters in the world. And no one has a right to say that no water babies exist, till they have seen *no water babies existing;* which is quite a different thing, mind, from not seeing water babies; and a thing which nobody ever did, or perhaps ever will do."

CHAPTER XII

The Origin of Life

No consideration of living things can be complete unless it includes a discussion of the origin of life. This is one of those primeval questions which have agitated the mind of man from the beginning of history. Some system of creation, some explanation for the beginning of living things, has been devised by even the most primitive peoples. Of course it is possible to suppose that living things have existed on the earth or elsewhere forever, that they had no beginning. But the difficulty of conceiving of anything without a beginning some time, somewhere, impels us to assume that there was a time when living matter did not exist.

105. **Explanation for Origin of Life.**—It has been suggested that living beings were created by some Supreme Being. This is perhaps the commonest answer; but it lies outside the province of science, since science cannot test it by observation or experiment. A second answer is that we do not know how life originated. This is a good scientific answer, if we do not imply that we will not seek for knowledge. It has been suggested by some distinguished men of science that minute and simple forms of life may have come to the earth from elsewhere, carried in the crevices of meteors or borne in cosmic dust. The probabilities are against such a solution, and, even if true, it merely shifts the problem to some other planet. Finally, it has been often suggested that simple living creatures have arisen and still arise by natural (as contrasted with supernatural) processes from non-living materials, without the intervention of previously existing living things. This has been called the *theory of spontaneous generation* or *abiogenesis*.

106. **Spontaneous Generation.**—This theory has had a long and interesting history; and the results of investigations concerned with its validity are responsible, though we may not realize it, for some of the commonest every-day features of our present civilization, as well as being of immense importance to scientific biology.

At first sight the theory seems to be supported by observed facts.

"It[1] is a matter of every-day experience that it is difficult to prevent many articles of food from becoming covered with mould; that fruit, sound enough to all appearance, often contains grubs at the core; that meat, left to itself in the air, is apt to putrefy and swarm with maggots.

"The philosophers of antiquity, interrogated as to the cause of these phenomena, were provided with a ready and a plausible answer. It did not enter their minds even to doubt that these low forms of life were generated in the matters in which they made their appearance. Lucretius intends to speak as a philosopher, rather than as a poet, when he writes that 'with good reason the earth has gotten the name of mother, since all things are produced out of the earth. And many living creatures, even now, spring out of the earth, taking form by the rain and the heat of the sun.' The axiom of ancient science, 'that the corruption of one thing is the birth of another,' had its popular embodiment in the notion that a seed dies before the young plant springs from it; a belief so wide spread and so fixed, that Saint Paul appeals to it in one of the most splendid outbursts of his fervid eloquence:—

" 'Thou fool, that which thou sowest is not quickened, except it die.' "

Aristotle, the greatest scientist and one of the greatest philosophers of that famous and highly civilized race, the ancient Greeks, believed that "Some plants are generated from the seed of plants, whilst other plants are self-generated. So with animals, some spring from parent animals according to their kind, whilst others grow spontaneously, and of these some come from putrefying earth or vegetable matter, as is the case with a large number of insects, whilst others are spontaneously generated on the insides of animals." Also "Lice are generated out of the flesh of animals," and "Sometimes putrefactions are set up in damp smoky ground, and hold the air, and thus mushrooms and the like will be produced." Aristotle was a true scientist, and founded his statements, as far as possible, on observed facts. And these particular beliefs seemed to him, and to many that came after him, to rest upon indubitable fact. He must have observed, for instance, that "mushrooms and the like" were frequently found growing in damp warm earth containing decaying vegetable matter.

[1] The quoted material in this section is taken mostly from Thomas Huxley's essay, *Spontaneous Generation* (in Lay Sermons, Addresses and Reviews).

"The proposition that life may, and does, proceed from that which has no life, then, was held alike by the philosophers, the poets, and the people, of the most enlightened nations, eighteen hundred years ago; and it remained the accepted doctrine of learned and unlearned Europe, through the middle ages, down even to the seventeenth century."

107. Redi.—But as Europe for the second time slowly emerged from barbarism, there came to be at least a few people who were unwilling to believe the accepted examples of spontaneous generation [2] without more definite evidence. An Italian, named Redi, first put the matter to the test of experiment in 1668. Redi's experiment was simplicity itself. He placed some meat in a jar, and covered the mouth of the jar with gauze. According to the current belief, the meat should have generated maggots as it putrefied. But no maggots appeared, though the meat putrefied as usual. It is obvious, therefore, that the gauze kept out whatever is usually responsible for the appearance of maggots.

"Nor is one long left in doubt what these solid particles are; for the blowflies, attracted by the odors of the meat, swarm round the vessel, and, urged by a powerful, but in this case misleading instinct, lay eggs out of which maggots are immediately hatched upon the gauze. The conclusion, therefore, is unavoidable; the maggots are not generated by the meat, but the eggs which give rise to them are brought through the air by flies."

Other similar experiments were made by Redi and by others, and gradually the old fables of spontaneous generation became discredited in the minds of thinking men.

108. Bacteria and Spontaneous Generation.—Then, in 1683, a Dutchman named Leeuwenhoek constructed a microscope more powerful than any before used; and with it he studied various

[2] Published recipes for the creation of life can be found. One such is as follows: Merely place in a box some cheese and a few rags, and set it away in a dark corner, and in a short time mice will be generated in the box. It is obvious to us today that the "facts" upon which this recipe rested were not very carefully observed facts! In those days, every sort of hearsay evidence was admitted as fact, and it is not surprising that there was a plentiful crop of such fables. Not only were living things generated from earth, meat, or cheese, but one sort of living thing sometimes sprang from another of a quite different sort. There was a certain tree, for instance, whose seeds, if they fell on the ground, became worms; if they fell in water, became geese. Such tales provoke our laughter—but to the people of those days they were most natural. And some of them still linger on. Many a small boy of today believes that horsehairs, if they fall into water, become worms or snakes.

objects, including some tartar from his teeth. What was his surprise to find in the tartar numerous "tiny animals that moved about in a most amusing fashion." Further study revealed them in all sorts of materials, especially in dead and decaying organic matter. What could be more sure, to the men of that day, than that these "tiny animals" or "animalcules,"[3] were produced from the dead matter in the process of decay? It was true that mice came only from preëxisting mice, and maggots from flies, but these microscopic animalcules, as anyone could observe, developed spontaneously from decaying organic matter. This could be demonstrated by experiment.

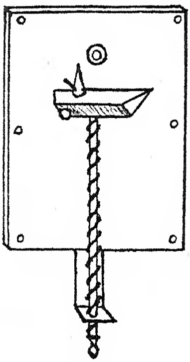


FIG. 124. Leeuwenhoek's microscope. The object to be observed was placed on the sharp pin on the table supported by the screw (by means of which its position could be changed). It was viewed through the lens mounted in the hole in the upper part of the upright board. (From Morrey, *Fundamentals of Bacteriology*, Lea and Febiger.)

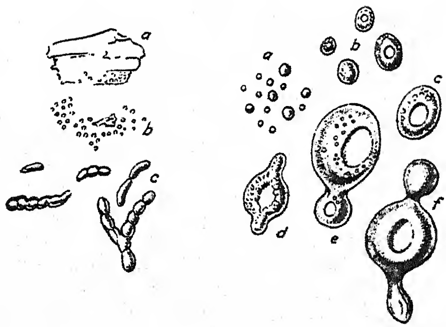


FIG. 125. Schleiden's conception of the origin of bacteria and yeasts. Left, granule of protein disintegrating into bits (*a* and *b*) which form animalcules or bacteria (*c*). Right, granules in currant juice (*a*) which gradually form yeast cells (*b* to *f*). (From Schleiden, *Principles of Scientific Botany*.)

109. Needham and Spallanzani.—In 1745 Needham, an English divine, placed some meat extract in a vessel, boiled it, corked and cemented the opening of the vessel, and heaped over it hot ashes. He argued that such treatment must kill all the living things in the meat extract and prevent any gaining entrance from the outside. When he examined the contents of the vessel, several days after preparing it as described above, animalcules were present, and Needham concluded that they must have been generated spon-

[3] We now call these infusorial animalcules germs or bacteria.

taneously from the inanimate organic matter in the vessel. Thus arose an entirely new theory of spontaneous generation—this time resting on what seemed to be the best scientific evidence.

But had Needham heated the contents of the vessel long enough and at a temperature sufficiently high to kill all the living things present, and had he sealed it tightly enough to prevent the entrance of animalcules from without?

With these questions in mind, an Italian abbé, Spallanzani, subjected in 1765 the results and conclusions of Needham to scientific criticism. He performed much the same sort of experiment, but, instead of corking the vessels containing the organic matter as Needham had, he sealed them by melting together the glass necks; and, instead of heating them as Needham did, he boiled the material for three-quarters of an hour. In these vessels no animalcules developed, and he concluded that spontaneous generation, which Redi had proved false for meat-maggots, was false also for infusorial animalcules.

110. Further Experiments.—However, the connection between gaseous oxygen and life had just been discovered, and the supporters

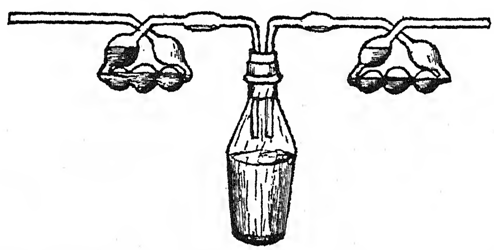


FIG. 126. Schulze's experiment. The bulbs at the right contain potassium hydroxide, the bulbs at the left sulfuric acid. The bottle contains the heated solution. (From Morrey, *Fundamentals of Bacteriology*, Lea and Febiger.)

of spontaneous generation suggested that no animalcules had developed in the flasks used by Spallanzani because they were completely sealed and the air necessary for life had not been admitted to them. Schulze and Schwann (1836 and 1837) contrived an apparatus in which air was admitted to the vessels only after it had first passed through red hot tubes or strong sulfuric acid, which would destroy any living things which might be in it;—and no living animalcules developed in the boiled infusions. It was claimed that the heat or the acid had changed the character of the

air so that it no longer supported life. In 1854 and 1859 Schroeder and Dusch found that no animalcules developed in the organic matter after it had been heated in a flask to which air was admitted

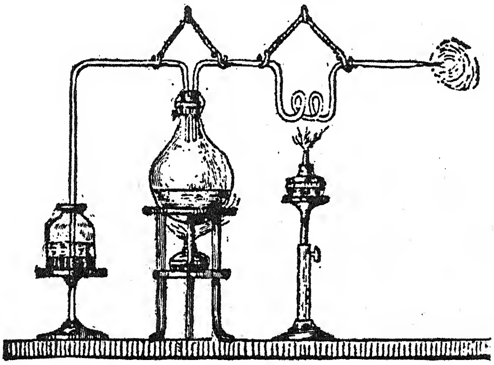


FIG. 127. Schwann's experiment. After the contents of flask had been boiled, air was admitted to it through the heated tubes at the right. (From Morrey, *Fundamentals of Bacteriology*, Lea and Febiger.)

only through a tube plugged with cotton. No one could conceive that the cotton, through which air had access to the contents of the flask, did more than filter out from the air discrete particles

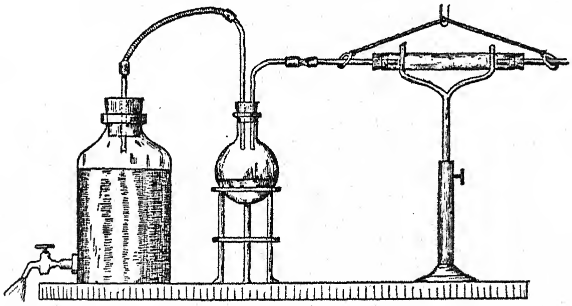


FIG. 128. Schroeder and Dusch's experiment. The aspirating bottle drew air into the flask through the cotton-filled tube at the right. (From Morrey, *Fundamentals of Bacteriology*, Lea and Febiger.)

which initiated the development of living animalcules in organic extracts. But there were still those who pointed out, quite properly, that it was necessary to prove that there were particles in the air which were alive or could produce life. Tyndall, an English

physicist, demonstrated in 1870 that "ordinary air is no better than a sort of stirabout of excessively minute solid particles; that these particles are almost wholly destructible by heat; and that they are strained off, and the air rendered optically pure, by being

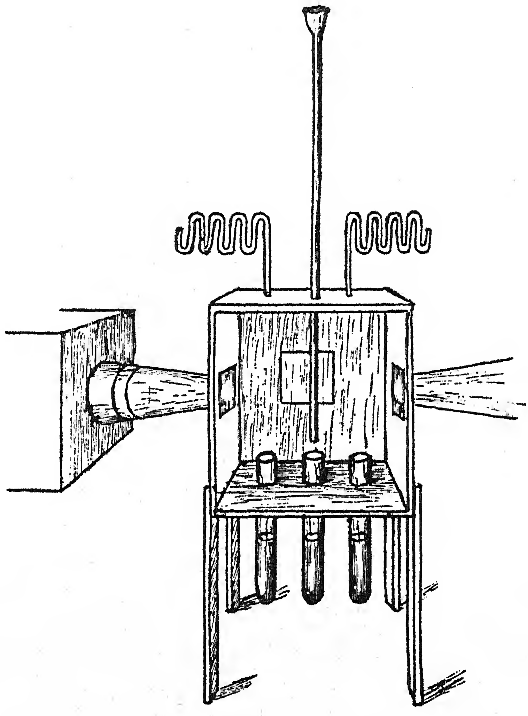


FIG. 129. Tyndall's box. One side is removed to show the construction. The bent tubes at the top permit free circulation of air. The beam of light sent from the lamp at the side was observed through the window at the back. The three tubes were filled by the pipette with an infusion and then boiled in an oil bath. (From the Popular Science Monthly.)

passed through cotton-wool." He showed also that boiled infusions left open to the air in a closed box, through which air circulated, did not show any growth of organisms provided the air was so free of particles that the path of a ray of light through it could not be seen.

111. **Pasteur and Spontaneous Generation.**—" But it remains yet in the order of logic, though not of history, to show that among these solid destructible particles there really do exist germs capable

of giving rise to the development of living forms in suitable menstrua. This piece of work was done by M. Pasteur in those beautiful researches which will ever render his name famous; and which, in spite of all attacks upon them, appear to me now to be models of accurate experimentation and logical reasoning. He strained air through cotton-wool, and found, as Schroeder and Dusch had done, that it contained nothing competent to give rise to the development of life in fluids highly fitted for that purpose. But the important further links in the chain of evidence added by Pasteur are three. In the first place he subjected to microscopic examination the cotton-wool which had served as a strainer, and found that sundry bodies, clearly recognizable as germs, were among the solid particles strained off. Secondly, he proved that these germs were competent to give rise to living forms by simply sowing them in a solution fitted for their development. And, thirdly, he showed that the incapacity of air strained through cotton-wool to give rise to life was not due to any occult change effected in the constituents of the air by the wool, by proving that the cotton-wool might be dispensed with altogether, and perfectly free access left between the exterior air and that in the experimental flask." He did this by drawing out the neck of the flask into a long narrow tube, which bent first down and then sharply up again (such a flask is now called the Pasteur flask). No life developed in the flask, although the tube was left perfectly open. The reason is, of course, that particles in the air which passes into the flask come in contact with and stick to the moist walls of the tube at the sharp bend, and never reach the organic contents at all; and this explanation could be true only for solid bodies. The last objection of the Abiogenists was that the "generative power" of the food had been destroyed by the heating. Pasteur's answer was simple and convincing. He shook a little of the liquid into the crooked neck; immediately the development of living organisms

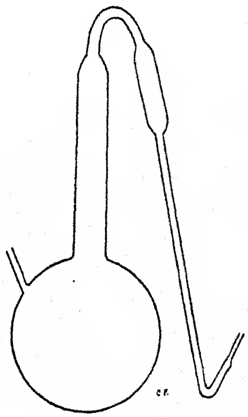


FIG. 130. A Pasteur flask. The short arm at the left is used to introduce the infusion into the flask. It is then hermetically closed and the contents of the flask boiled, the bent tube at the right being left open.

began in it. This showed that the liquid had not been changed, and, furthermore, that there really were living germs caught in the crook of the tube.

Even yet the long controversy was not at an end. An English doctor, Bastian, obtained living bacteria in liquids which had been boiled and from which air had been properly excluded. He used liquids far more alkaline than those that had been previously used; and so thought he had discovered conditions under which life did originate from lifeless matter. These results were brought to the attention of Pasteur. A poorer scientist would have scorned them as being opposed to his own experiments and therefore impossible; or would have written a treatise to prove them wrong. Pasteur, however, being a good scientist, subjected the experiments to test in his own laboratory; and found that living things actually did appear even after prolonged boiling of the liquid and proper exclusion of air. Far from arguing, however, that this result proved false all his other conclusions, he reasoned that living germs must have persisted in spite of the boiling. He repeated the experiments, substituting, for the customary boiling heat under pressure, a temperature of 120°C.; and no bacteria were "generated." Bastian's experiments had proved something—but not what he thought. When subjected to more complete tests, they proved, not that life is generated spontaneously, but that certain living things are not destroyed by a temperature of 100°C. under certain conditions, but can be destroyed by a temperature of 120°C.[4]

112. **Scientific Attitude toward Spontaneous Generation.**—Evidence for spontaneous generation is still lacking. No single case of the development of a living thing from non-living material has ever been observed. This has been reduced to the dictum *vivum e vivo* or *life from life*. This does not mean that abiogenesis does not occur, nor that we may not some day observe its occurrence. It means that, *so far as our experience goes*, living things come only from preëxisting living things. It may be that some day, with increased knowledge of the make-up of living things, and with increased knowledge of the structure of non-living material and of the means of controlling it, some sort of simple living stuff may be made in the laboratory from lifeless material. Every supposed example of such a thing must be critically examined with the

[4] These conclusions were confirmed about this time by the discovery of the bacterial spore and its resistant character. See the later chapter on bacteria.

history of the theory of spontaneous generation in mind and with full knowledge of the ways in which its supposed occurrence has been proved fallacious. Neither does our attitude toward spontaneous generation in the present mean that it has not occurred in the past. It is necessary, in fact, if we are to seek for a scientific answer to the problem of the origin of life, to assume that life did originate, at least once, from non-living matter.

113. **Hypothesis for the Origin of Life.**—These considerations lead us to the science of Geology, to ask what may be learned, or guessed, of the possible origin of life from non-living material in past ages. The fossils found in the rocks extend back to some of the oldest rocks, becoming, however, fewer and simpler as we go back. Living beings may well have existed prior to the time when the oldest stratified rocks were laid down, if we suppose, as seems probable, that the first living organisms were small, simple in structure, and such as would not easily be preserved in the rocks. It seems reasonable, therefore, to place the first origin of life very far back in the geologic past.

According to one widely accepted theory of the formation and growth of this earth, many millions of years ago the earth was being bombarded by a fall of relatively small masses, called meteorites or planetesimals, which as they fell into the earth added to its size. It has been suggested that the conditions and the variety of inorganic substances which would be necessary for the origin of living matter may have been present during this fall of meteorites. Under these circumstances, which were different from any that have existed since then, the proper elements may have been combined into the first living matter. This may have occurred at many times and in many places; but the factors necessary for such a complex event must have been so numerous that the probability of their being brought together even once was very small, and the chances against such an event taking place more than once were enormous.

The formation of the first living matter may have occurred, perhaps, in the water which occupies the tiny spaces in soil—water protected from the injurious rays of direct sunlight and from the severe mechanical action of moving bodies of water. We may suppose that in these conditions it was possible for certain relatively very simple masses of protoplasm to survive and multiply. Perhaps these first organisms resembled the bacteria (see Chapter XIII) in

size and structure, and were able, like a few of the modern bacteria, to obtain energy from inorganic compounds; or perhaps they had chlorophyll, like the present blue-green algae (see Chapter XVIII), which have a simple, bacterium-like structure. These suppositions harmonize with the fact that the earliest traces of life found in the rocks are of small bacterium-like cells. From these first organisms others may have evolved, more highly differentiated, and perhaps using the remains of the first ones for food. Some of them might be carried by water currents into the oceans or to muddy shores, and there continue life and evolution.

It has been suggested that such things as the filterable viruses (see page 187), which seem to exhibit some qualities of living matter without being formed into recognizable cells or other bodies, may represent the most primitive form of life; may even represent living matter recently formed from non-living matter. All these theories and suppositions, though highly speculative, and lacking direct proof, may serve to keep our minds open to the realization that it is not only possible but probable that life once arose spontaneously from non-living matter, and that it is even possible that the same event may occur under modern conditions and may some time be discovered.

114. The Significance of Experiments on Spontaneous Generation.—The conclusion from the experimental work on spontaneous generation—*vivum e vivo*—has been of immense importance to mankind. We assume its truth every time we "preserve" some article of food or undergo an operation in a modern hospital. If food is heated to destroy bacteria and canned so as to exclude the bacteria in the air, we assume that none will develop in it spontaneously and spoil it. We assume that if bacteria are kept from an open wound none will develop spontaneously within the body and cause an infection. These assumptions are justified by the results. In addition, our entire way of thinking on biological matters, our theory of evolution, our notions of heredity and reproduction are all based on the supposition that life comes at present only from preëxisting life.

The history of the famous spontaneous generation question illustrates well a process that has taken place in all biology—in all science. Every statement that we make today, every idea we hold for truth, has a history behind it. Our conviction, that at present life comes only from life, rests on the experiments of Redi,

of Spallanzani, of Schroeder and Dusch, and of many others—finally capped by the work of Pasteur. It was Pasteur's good fortune to gather in his hands the tangled ends of controversy, and, with his beautiful and convincing series of experiments, to discover the truth hidden therein. But this would not have been possible without all the others. Science is not the result of one man's thinking—it is the result of the slow accumulation of evidence from many sources, and the gradual elimination of error. And we are not yet at the end of this subject or of any other—there is still evidence to be obtained, there are still errors to be eliminated.

CHAPTER XIII

Bacteria

A GREAT deal of information about the bacteria has accumulated since the time of Leeuwenhoek, who first observed them. Large books are filled with descriptions of the many different kinds of bacteria, with directions for their cultivation and with the details of what they do and its significance for us. Many men devote the greater part of their lives to studying or working with the bacteria. We can summarize briefly part of the knowledge of them which has accumulated.

115. **Morphology.**—A bacterium (plural, bacteria) consists of but one cell; and that cell is usually an extremely tiny one. The average length is perhaps 0.005 millimeter, or 1/5,000 of an inch. There is, however, an enormous variation in size. The smallest bacteria are about 0.0002 millimeter in diameter, near the limit of microscopic visibility. The largest are perhaps 500 times as big. Individually the bacteria are too small to be seen with the unaided eye. It is only when hundreds or thousands of them are together that we can see them; they then form a translucent, whitish, pinkish, or yellowish mass, either dry or slimy in character.

Bacteria are of three different shapes; some are spherical, some oval or rod-shaped, some have the form of a curved or spirally twisted rod. The spherical bacterium is known as a *coccus* (plural, *cocci*), the rod-like as a *bacillus* (plural *bacilli*), and the curved or twisted as a *spirillum* (plural, *spirilla*).

Many bacteria (mostly bacilli and spirilla) have the power of motion. Such bacteria, when viewed through the microscope, dart hither and thither with what seems to be considerable speed, sometimes in straight lines, sometimes very erratically. The motion is due to tiny, delicate threads of protoplasm called *flagella* (singular, *flagellum*), which project from the body of the bacterium, and which lash to and fro in the surrounding water. The number and position of these flagella vary on different kinds of bacteria. Sometimes there is but one, at one end of the cell; sometimes there is one at each end; or a tuft at one end or at each end; or they

may be scattered all over the cell.[1] The flagella of the living bacteria are not visible. They can be demonstrated only by special methods of staining.

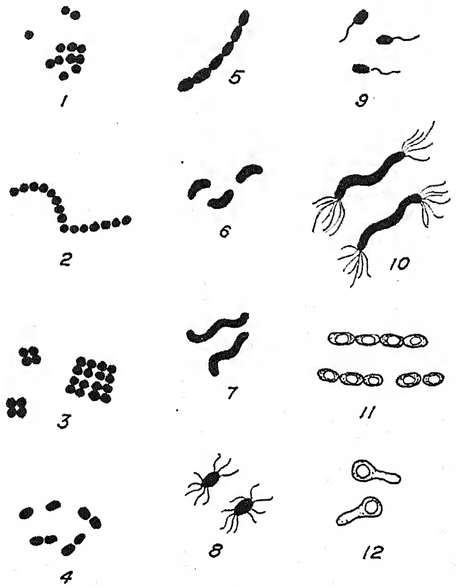


FIG. 131. Types of bacteria. *1*, *2*, *3*, examples of the coccus type; *4*, *5*, bacillus types; *6*, *7*, spirillum types; *8*, *9*, *10*, bacteria with flagella; *11*, *12*, bacteria containing unstained spores, which appear clear.

Bacterial cells are so small that it is not easy to distinguish their internal structures. The question whether or not a nucleus is present is still not entirely settled. In most of the bacteria no distinct nucleus can be seen. The entire cell is easily colored with dyes that usually stain nuclei; and in the protoplasm lie many minute granules, sometimes thought to be chromatin granules. It is believed, therefore, that nuclear material is present, but scattered through the cell instead of being organized into a definite nucleus as in most other cells. In a few kinds of large bacteria a definite nucleus has been observed.

[1] Besides the motion caused by the activity of flagella, many bacteria have a vibratory movement; they vibrate rapidly back and forth in the water without changing their general location. This kind of movement, however, is not limited to living things; any particles sufficiently small and suspended in water move in exactly the same way. Such vibrations are called *Brownian movement,* after the man who first described them.

Besides the particles just mentioned, small granules of food are sometimes to be seen in the protoplasm. Frequently there is no vacuole; and there are never chloroplasts, though red, yellow, or purple pigments may be present. The cell contents are surrounded by a delicate cell wall,[2] the material of which differs from that of the cell walls of most other plants. The outer layer of the wall is of a different nature from the inner part, being often more or less slimy; and it is because of this slimy coat that bacterial cells often stick together in groups. The morphology of a bacterium is therefore very simple. It consists essentially of a minute bit of protoplasm surrounded by a cell wall.

116. Physiology.—Because of the lack of chlorophyll one of the activities found in the plants which we have already studied does not occur in the bacteria; they are unable to carry on photosynthesis.[3] But like all living things they require food. This food they secure as animals do from some outside source. It may be secured from the dead bodies or living protoplasm of plants and animals or it may be materials derived from plants and animals, such as sugar or starch or fat or protein. Almost every imaginable sort of organic material—meat, leather, wood, gelatin, even formaldehyde—may be used as a source of food by some kind of bacteria.

In addition they require water, certain mineral salts, and some sort of nitrogen. Many bacteria can secure the nitrogen they need from compounds of nitric acid or ammonium, as a green plant does, others require organic nitrogen as animals do, a few can use gaseous nitrogen. Some of the latter live free in the soil, others live in the roots of leguminous plants, as has been described earlier. These *nitrogen fixing* bacteria are very important to us, because they are the chief natural means by which gaseous nitrogen is returned to a combined form usable by other plants and by animals. Decay

[2] It is because of the possession of a cell wall that the bacteria are classed as plants, although they resemble animals in their lack of chlorophyll and in their power of movement. Some of the one-celled organisms have characteristics both of plants and animals, so that there is no one mark which distinguishes all plants from all animals; the presence of a distinct cell wall, however, serves best to separate plants from animals.

[3] A few kinds of bacteria oxidize inorganic materials such as simple compounds of nitrogen, sulfur or iron and utilize the energy secured in this oxidation to synthesize carbon dioxide and water into organic material. They do not require a supply of food from without. This process is called *chemosynthesis*. These kinds of bacteria are called *autotrophic* as contrasted to the *heterotrophic* bacteria, which require food from some outside source.

and burning change some of the combined nitrogen into gaseous nitrogen. If there were no way of reversing the process all nitrogen would in time be locked up in the gaseous form.

Some of the bacteria require gaseous oxygen (are *aërobes*), some cannot live in the presence of gaseous oxygen (are *obligate anaërobes*), and still others can live with or without gaseous oxygen (are *facultative aërobes*).

Since the bacterium is surrounded by a wall, the food which it absorbs must be in solution. Enzymes, which the bacterium excretes into the substrate on which it grows, digest the food and make it available for use. In this way bacteria may use wood, starch, meat or other insoluble material.

117. **Importance of Bacteria.**—Just as in other living things, the foods used by the bacteria either furnish energy or are used for building material. The energy stored in the food is released by the destruction of the food material in the process of respiration; but the respiration of bacteria frequently differs in certain respects from that of the green plant and the animal. The food of the latter is usually completely broken down into carbon dioxide, water, and such simple compounds. The products of bacterial respiration are frequently more complex substances; sugar, for instance, may be decomposed into lactic acid or acetic acid or alcohol. The sugar in milk is transformed by the lactic acid bacteria into lactic acid. The products of the digestion and respiration of one kind of bacteria may be broken down still further by other sorts, with the result that the body of a plant or animal composed of many complex organic substances may be changed eventually by the digestive and respiratory activity of bacteria into water, carbon dioxide and mineral salts and disappear as such. This process we call *decay*. While in particular cases decay may be disadvantageous, on the whole it is a necessary process, for, without it, if life could continue at all, the surface of the earth would be covered with a layer many feet thick of the dead bodies of plants and animals. Sometimes the results of bacterial digestion and respiration are malodorous, in which case we call the process *putrefaction*. Sometimes the products are poisonous, for instance the ptomaines formed in meat by the action of bacteria. In still other cases the products may be useful to us. Familiar examples are the formation of lactic acid in the souring of milk, upon which depends the making of butter and cheese; and the production of acetic acid from alcohol in the making of vinegar.

Some kinds of bacteria secure their food from the living bodies of plants or animals—growing between the cells or within the cells. We call any organism which does this a *parasite* and the plant or animal from which it secures its food is the *host*. Other bacteria use as their food organic material which is not alive. These bacteria and other plants which live in the same way we call *saprophytes*.

118. Bacteria Causes of Disease.—Parasitic bacteria rob the host of food, and often produce extremely poisonous substances called *toxins* which may kill the host. Such parasitic bacteria cause disease, by which we mean an abnormal condition of a plant

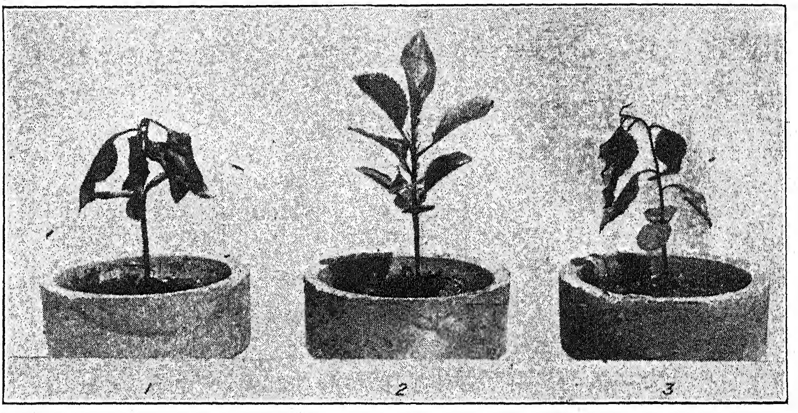


FIG. 132. A bacterial disease of plants, pear blight, caused by *Bacillus amylovorus*. Plants 1 and 3 were pricked with a needle covered with the bacteria two days before being photographed; plant 2 was not inoculated. (Courtesy of W. G. Sackett and the Colorado Agricultural Experiment Station.)

or animal. Pneumonia, typhoid fever, cholera, anthrax and many other diseases are caused by bacteria. Bacteria, however, are not the causes of all diseases.

That bacteria cause disease has been known only a short time. In the days when spontaneous generation was widely believed to be a fact, it was thought also that the bacteria found in the body of a diseased animal were produced by the disease. The disease was thought to be caused by demons or by an unbalanced condition of the "humors" of the body. It is largely due to the experiments of Pasteur that the rôle of bacteria in disease is understood. It was Pasteur who learned to take bacteria from a diseased animal,

grow them in culture solution, and, by injecting some of them into a healthy animal, again obtain the disease. He showed, moreover, that one particular type of disease is associated with one particular type of bacterium—the organism which causes tuberculosis does not, in another individual, cause typhoid fever.

While Pasteur was studying a deadly disease of chickens known as chicken cholera, he chanced to inject into some chickens a culture [4] of the bacteria which had been forgotten and had lain on the laboratory table some time. To his surprise, the chickens, instead of dying as usual, were hardly affected. Yet the bacteria were still alive. He then injected into the same birds some of a fresh culture; and was still more surprised when the result was only a mild sickness, followed by recovery. This same culture, when injected into other chickens, caused rapid death; yet the chickens previously injected with the old culture resisted the disease.

This was the discovery of the great principle of vaccination, by the application of which to many other diseases hundreds of lives, not only of domestic animals but of human beings, have been and are still being saved.

Previously to this Jenner, an Englishman, had shown that inoculation of a human being with cow-pox caused a very mild sickness and caused the patient to become immune to smallpox. Even before Jenner's time, physicians had known that infection from a mild case of smallpox often caused a very mild attack and conferred protection against the disease. Nothing, however, was understood of the principles involved; and they were therefore not applied to other diseases.

Pasteur's discovery came as an accident. Yet only in skilled hands is an accident fruitful. Pasteur set about the study of other diseases in the hope of finding vaccines for them. After many experiments he succeeded in duplicating his chicken cholera results for anthrax, a disease of cattle and sheep which was then causing enormous losses to farmers. Pasteur isolated and studied the anthrax bacterium, studied its transmission from host to host, grew it in cultures, found a way of weakening the culture so that it conferred immunity against fresh cultures; all in spite of a general explosion of indignation and opposition from the veterinarians of

[4] Any growth of plants on materials which may be used in a laboratory is called a culture.

the day, who could not tolerate this upstart biologist with his fantastic ideas about "microbes." They challenged him to come out from his laboratory and show them, as practical men, what his "theories" amounted to. Pasteur accepted the challenge. Sixty sheep were provided, of which twenty-five were vaccinated by Pasteur. Then, in the presence of a large crowd of farmers, reporters, and veterinarians, fifty sheep, including the twenty-five vaccinated ones, were inoculated with a fresh deadly culture of anthrax. A week later twenty-five were dead; the twenty-five vaccinated sheep were calmly cropping the grass and in as good health as the ten animals that had not been treated.

Pasteur carried his studies from anthrax to rabies, then a dreadful and ever present danger. In 1885 he treated a boy who had been severely bitten by a mad dog; the boy, instead of dying in the agonies of rabies, recovered completely. Since Pasteur's time, similar methods, with similar results, have been applied to many other diseases.

We are still ignorant of the complete explanation of these facts. What we know is as follows: The toxin formed by the parasite causes the production in the blood of the host of an *antitoxin*, which tends to neutralize in some way the toxin. But if the toxin is very abundant the antitoxin may not be sufficient to protect the host from death. However, the injection of a weakened culture apparently causes the production of quantities of antitoxin, which overcomes the toxin formed. Much of the antitoxin remains in the blood, often for many years, and is able to counteract any new invasion by the bacteria before the latter become abundant. Sometimes antitoxins of some sort exist naturally in the blood—so that some persons are naturally immune to certain diseases.

119. Reproduction of Bacteria.—The bacterial cell, like all unspecialized cells, has the ability to divide at regular intervals. When the embryonic cell of a root of a green plant divides, the result is an increase in the number of cells (and subsequently in

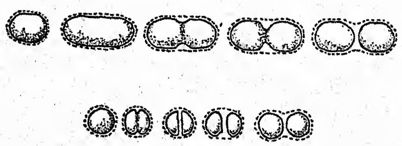


FIG. 133. Reproduction of bacteria by fission. Above, a bacillus form; below, a coccus. (Redrawn from Marshall, *Microbiology*, P. Blakiston's Son and Co.)

the size) of the root. When a bacterial cell divides, the resulting cells are, like the parent cell, complete plants, which may separate and lead lives independently of eath other.[5] This is true also when the bacteria formed by division remain attached. Such groups of one-celled plants, formed by the division of one parent cell, are termed *colonies*. It should be noticed that each member of a colony remains unspecialized, capable of existence independently of the other members; it is in fact an *individual* plant, by which we mean a complete plant, possessing or capable of forming the structures characteristic of that kind of plant, and clearly distinct from all other individuals. Such a group of cells as we have called a colony must not be confused with that which constitutes such a plant as a tree, where the cells are dependent upon one another in various ways, and each cell forms only a small part of the individual, which is of course the whole tree.

Cell division in a many-celled plant, therefore, is usually one of the processes of *growth*—the development of an individual; in one-celled plants cell division is a means of *reproduction*—the formation of *new* individuals. One thing is common to both processes—the formation of new cells. In some sorts of plants the new cells remain attached and many become specialized and dependent on each other in various ways; we then speak of the whole mass of cells as an individual plant. In others, the new cells separate and each lives independently of the others (or, if they remain attached, they are not dependent upon one another), and we call each cell an individual plant.

Under certain conditions some bacteria form bodies known as *spores*. This takes place through the formation within the original cell wall of a new wall surrounding the protoplasm of the cell, which has become contracted into a small space; or, in some bacteria, surrounding a portion of the original protoplasm. In some kinds of bacteria more than one spore are formed in a cell. The new cell thus formed may be greater in diameter than the original cell, so that the wall of the latter is bulged out and becomes of a spindle or drumstick shape. The old cell wall and whatever

[5] The bacilli divide usually in a plane perpendicular to their length, so that the daughter cells are end to end and a chain of cells is formed. The cocci may form similar chains by successive divisions in parallel planes; or small groups of four or eight cells symmetrically arranged; or groups of cells arranged in no definite pattern. The division of a single-celled individual into two protoplasts of equal size is called *fission*.

protoplasm may remain outside of the new cell disintegrate, and the new cell, or spore, is liberated. The spore, because of its thick wall and its low water content, is very resistant to heat and cold and lack of moisture, so that bacteria in this form can endure conditions which other living beings cannot tolerate.[6] When a spore comes again into circumstances favorable to more active life, the contents escape from the wall and take on the usual form characteristic of the particular type of bacteria (some do this without shedding the wall).

Each spore thus produces again (re-produces) a bacterial cell of the type from which it was derived. We may speak of this,

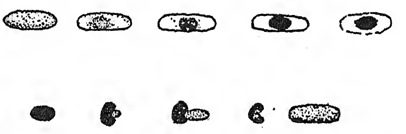


FIG. 134. Formation and germination of a bacterial spore.

therefore, as a method of reproduction. This illustrates that reproduction, as here defined, does not *necessarily* increase the number of individuals.

These reproductive bodies we have called spores. Spores of various types are met with in most other plants also, and it becomes necessary to find a general concept for the term. The word spore has come to mean a cell (or sometimes a group of a few cells) capable of development into the mature form of the plant in question, and more or less limited to that function (that is, it does not itself, while yet a part of the parent organism, perform the vegetative[7] activities characteristic of that organism). As we shall see later, spores are specialized in a variety of ways. They are not necessarily invested with a heavy wall. Because of their manner of formation *within* a parent cell, bacterial spores are known as *endospores*.

[6] The digesting growing bacterial cell is called the *vegetative* cell as contrasted to the spore which is, as is pointed out, a *reproductive* cell. The vegetative bacterium is killed by a temperature of 100°C. The spore is not killed by this temperature. A temperature of 120°C. for 20 minutes will kill spores and vegetative cells. If a vessel containing water and food is plugged with cotton and heated to 120°C. for 20 minutes, all living things within it are killed and the medium is said to be *sterile* and remains sterile until living organisms are introduced into it from without.

[7] Activities concerned with growth, nutrition, etc., as distinct from reproduction.

120. Distribution of Bacteria.—The bacteria are probably the most universally distributed of all living things. This is due partly to their diverse food requirements. Many bacteria are more or less limited in their diet; but there are so many kinds that scarcely any food exists that cannot support a good many types of bacterial life. Ordinary market milk, for instance, may contain from 1 to 10 millions of bacteria in each cubic centimeter—usually all, fortunately for us, harmless to mankind. Yet, because of the extremely small size of each bacterium, if all the bacteria in a quart of milk could be gathered into one mass, they would form an object probably not much larger than a pinhead. The wide-

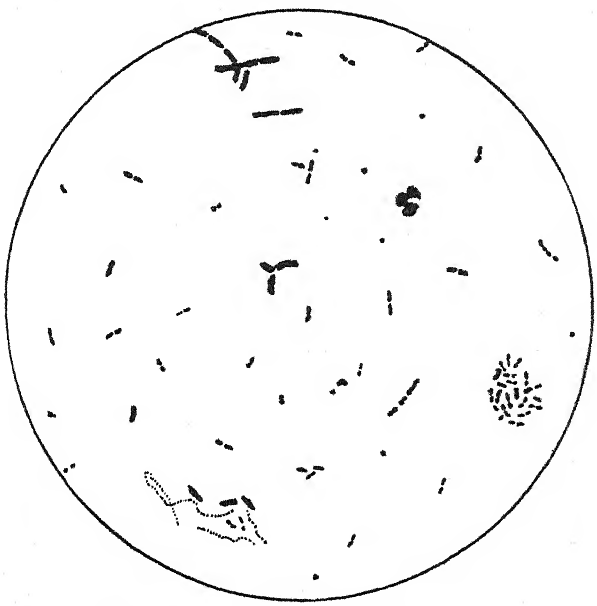


FIG. 135. Microscopic preparation of bacteria in milk containing 80,000,000 bacteria per cubic centimeter and nearly sour. ×400. (Redrawn from Conn.)

spread occurrence of bacteria is partly due also to their minute size, owing to which they can be easily carried in the air. They are found in the air free or adhering to dust particles, or in minute drops of water such as those which form clouds or mists. The quantity of bacteria in the air varies greatly. Large numbers are found in the air of city streets, stables, barns, and farmyards,

where there are quantities of dust. Few or no bacteria are found in the clear air of mountain tops, where the air is almost free from dust.

121. Counting Bacteria.—The rapidity with which bacteria reproduce is another reason for their commonness. This is illustrated by the ordinary method of growing bacteria in covered dishes (often called plates or Petri dishes) containing agar, a semi-

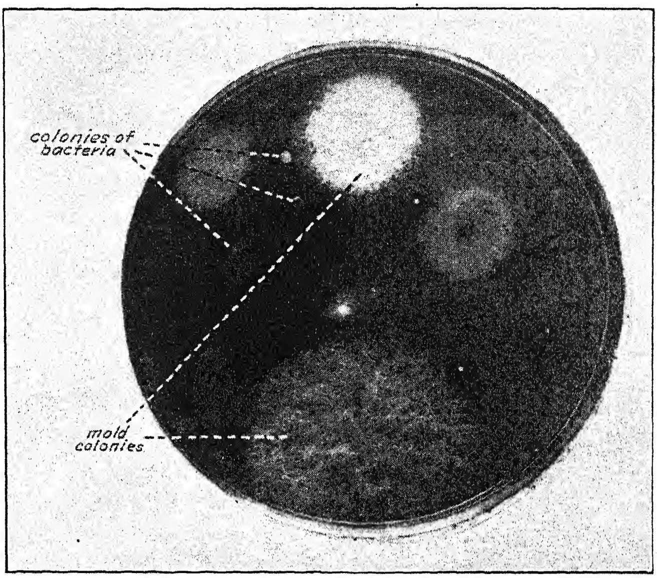


FIG. 136. Plate showing colonies of bacteria and molds which grew from cells or spores which fell into the plate from the air.

solid jelly-like material, in which are dissolved suitable food materials. If such a plate is sterilized—that is, heated to such a degree that all the bacteria and other living things in it are killed—and then opened to the air for a few minutes, a few bacteria will probably settle on the surface of the agar. They are, of course, quite invisible—the plate appears the same as before exposure. But after it has been kept a day or two at a temperature suitable for bacterial growth, spots begin to appear, usually more or less round and flat and of various colors. Upon examination under the microscope, these prove to be masses of enormous numbers of bacteria. Each mass has resulted from the reproduction of one

original bacterium which came from the air. The bacteria necessarily remained together in a colony because of the semi-solid consistency of the agar on which they grew.

This fact is used [8] in order to count the number of bacteria present in a certain quantity of food—for instance milk. It would be difficult to count under the microscope all the bacteria present in a small drop of milk, many of them being in constant motion; even if they were killed, it would be hard to avoid counting the same cell twice or missing some of them.

122. **Filterable Viruses and the Bacteriophage.**—It used to be said that the bacteria are the smallest living things. It is now known that certain diseases (*e.g.*, mosaic and smallpox), both of plants and animals, are caused by what is known as a *filterable virus*. This is a liquid which does not lose its power to cause the disease even when passed through the finest filters, which would remove bacteria. The microscope discloses in such a liquid no evidence of organic bodies. Yet it causes disease (whence its name virus, which means "poison") in a manner similar to the production of disease by bacteria, and apparently multiplies itself within the body of the host. We have as yet no real evidence from which to decide whether this thing is alive or not. It is quite possible that there are living things so small that they can pass the finest filters and are invisible under the highest magnification of the microscope. Of such nature may be the mysterious *bacteriophage*, a substance, whether living or not we do not yet certainly know, which destroys bacteria (whence its name, which means "bacterium eater"). The bacteriophage is believed to be the cause of the resistance of certain animals to certain diseases. And it may explain how running water "purifies itself" of bacterial life, even below points where sewage runs into it. The purifying agent may be the bac-

[8] What is actually done is this: One cubic centimeter of milk is measured out and mixed with 99 cubic centimeters of sterile water. One cubic centimeter of this mixture, which of course contains 1/100 the quantity of bacteria present in the original cubic centimeter of milk, is again mixed with 99 cubic centimeters of sterile water. A cubic centimeter of this mixture now will contain 1/10,000 the number of bacteria present in the original cubic centimeter of milk. This is mixed with some sterile agar containing food, and the mixture is poured into a Petri dish and allowed to harden. After a day or two at a suitable temperature there will be a number of colonies present in the plate. The number of colonies can easily be counted, and, since each one represents a single bacterium, this gives the number present in the milk ten thousand times diluted with water. Multiplying this by 10,000, we have the number of bacteria present in the original cubic centimeter of milk.

teriophage. If this is true, such waters may contain bacteriophage harmful to the bacteria which cause certain human diseases, and thus have an actual healing value. Perhaps this is the explanation of the fabled "healing power" of the Ganges, the Holy River of India. It is interesting also that in the old days muddy Thames water was preferred by the British navy for use on shipboard on account of its "self-purifying" and healthful qualities when kept a long time. Nothing, of course, was then known of the bacteriophage; but many facts, which come afterwards to be scientific principles, are used long before they are understood—as, for instance, the use of "mother" in vinegar making and of yeast in baking and brewing.

CHAPTER XIV

Yeasts

123. **Morphology.**—Another group of microscopic plants is composed of the yeasts, which resemble the bacteria in many respects, but are different in other respects, and therefore are not bacteria. The individual yeast plant consists of a single cell which is usually egg-shaped, ellipsoidal or spherical. Most kinds of yeasts are many times larger than the bacteria, though still microscopic in size. They are from 0.001 to 0.005 mm. wide and 0.0015 to 0.009

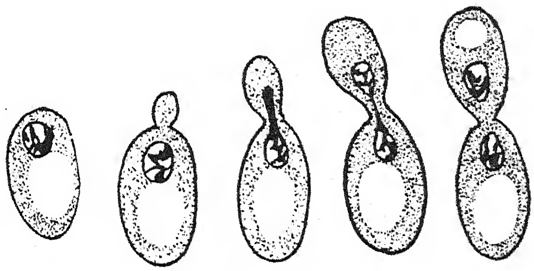


Fig. 137. Reproduction by budding. Yeast cells stained to show nucleus. (Redrawn from Guillermond, *The Yeasts*, John Wiley & Sons, Inc.)

mm. long. Each cell has a thin but definite wall, which is composed of a material called yeast cellulose. Microscopic examination reveals within the cell one or more vacuoles, some granules, oil drops, and a clear cytoplasm. A nucleus is present, but is not visible unless the yeast cell is especially stained. There are no plastids of any sort, though some kinds of yeast contain a pink pigment.

124. **Physiology.**—The lack of chlorophyll has the same result for the yeast as it has for the bacteria. A yeast plant, to live, must be supplied with organic material—usually sugar. In addition to sugar, yeast requires water, and inorganic salts, particularly nitrogen compounds and phosphates. A plentiful supply of gaseous oxygen, if other conditions are favorable, makes the yeast grow

rapidly, but it may live and grow slowly anaërobically. Under conditions where the oxygen is limited the respiration of the yeast results in an incomplete destruction of the sugar, alcohol and carbon dioxide being formed. This is the familiar alcoholic fermen-

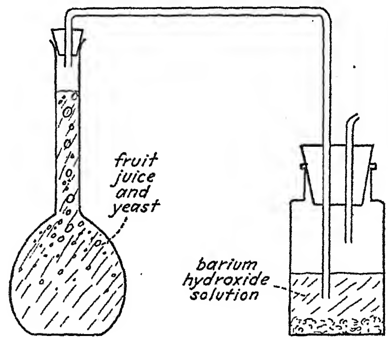


FIG. 138. A simple apparatus for demonstrating the production of carbon dioxide by yeasts.

tation, which is actually the result of anaërobic respiration by the yeast plant. The process may be represented in this way.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \underset{\text{forms}}{=} \underset{\text{carbon dioxide}}{2CO_2} \underset{\text{and}}{+} \underset{\text{ethyl alcohol}}{2C_2H_5OH} + 25{,}000 \text{ calories for every 180 grams of glucose}$$

This change is accomplished by an enzyme, zymase, formed and retained in the yeast cell.

125. Importance.—Economically this is an important process. The alcohol has many industrial and medicinal uses and the carbon dioxide is responsible for the rising of bread, the bubbles of gas formed by the yeast being caught and held by the dough. Some kinds of yeasts form substances of particular flavors. Different sorts of yeast also vary in the amount of alcohol they form before its accumulation inhibits their growth. So some kinds of yeasts are used in bread making, others in brewing, and still others in wine making or in the production of alcohol for industrial purposes.

Although alcoholic fermentation has been known since the beginning of history, the knowledge that yeast is responsible for the fermentation dates from about the middle of the last century

and resulted from the investigations of Pasteur on spontaneous generation. Previously to that the yeast plants were considered to be the result of fermentation rather than the cause.

126. Reproduction.—The growth of a yeast cell results in some increase in size but not an indefinite increase. A portion of the wall softens and is pushed out into a lateral outgrowth (bud). This increases in size; it may reach the size of the mother cell from which it was formed. As the bud is formed the nucleus in the original cell divides and one of the two nuclei passes into the

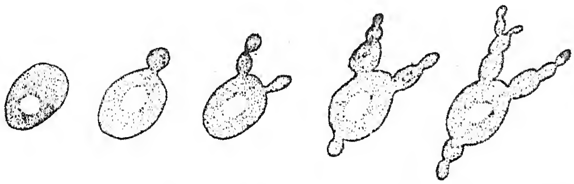


FIG. 139. Colony formation by rapidly growing yeast. Nuclei not stained.

bud. The bud is therefore a new cell. A single cell may produce more than one bud at the same time and the buds may bud in their turn. Eventually a wall forms across the opening which connects the bud with the mother cell, and the bud breaks loose and lives independently. The budding of yeast is evidently a method of reproduction. A yeast cell with its attached buds is a colony. Reproduction by budding occurs in most kinds of yeast, though there are some which reproduce by fission.

Under certain circumstances, particularly when food is limited and oxygen abundant, yeast may form endospores. From two to twelve, usually four, endospores are formed within the wall of a single yeast cell. Each spore contains a nucleus, some cytoplasm and food material, and is surrounded by a rather heavy wall. Like the endospores of bacteria, the yeast in this form is capable of resisting a degree of drought or heat which would kill a vegetative cell. The wall of the mother cell in which the spores were formed decays and the spores are freed. In the presence of plenty of water and other conditions for growth the protoplasmic contents of the spore eventually enlarge by water absorption, crack the wall and escape as a vegetative yeast cell. This renewal of growth by a dormant body we call *germination*.

Cell division and spore formation are the only two ways that have been found for the reproduction of yeast. Every yeast cell we see has been derived from another previously existing yeast cell

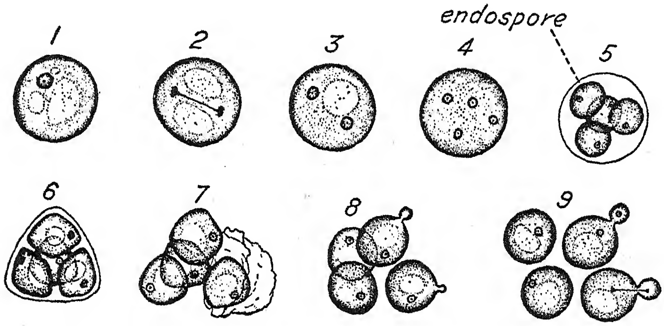


FIG. 140. Formation and germination of yeast endospores. Nuclei stained. (Adapted from Guillermond, *The Yeasts*, John Wiley & Sons, Inc.)

by budding (or fission in some yeasts) or by the germination of a spore formed by a yeast cell. Those cells in turn were derived from others and so on back to the beginning of yeast cells.

CHAPTER XV

Bread Mold

If a piece of bread is placed in a moist, fairly warm place, it "molds." A delicate fuzzy growth, of a white, green, or black color, appears on its surface; and this is usually accompanied by a

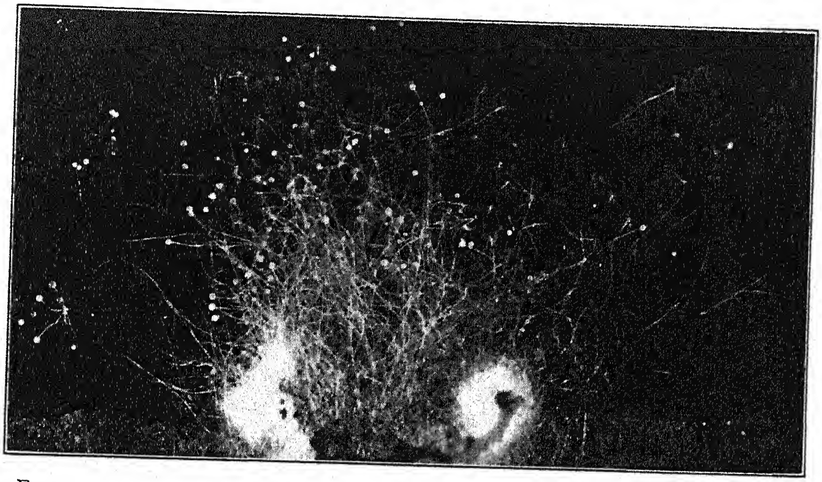


Fig. 141. "Bread mold" growing on a piece of bread. The sporangia are young and white. ×6.

musty odor. The same thing happens to other kinds of food—jam or jelly, syrup, fruit, and so forth.

If the mold is studied with a microscope, it is found to consist of innumerable delicate threads, branching in all directions, each bounded by a thin wall, and filled with a granular semi-liquid substance containing various clear spaces and denser particles and easily recognizable as living protoplasm. The mold is a living plant. It grows, digests, respires, reproduces. Its presence on the bread is accounted for in the same way as the presence of bacteria in decaying food;—it arrives from the air, in the form of a minute bit of protoplasm, a spore. Like the bacteria, this plant has no chlorophyll (even the green varieties owe their color to a

quite different sort of pigment), and its food is derived from another plant or from an animal. It differs from bacteria, however, in its comparatively enormous size and in its form.

There are many distinct kinds of plants which have this same general structure and cause what is popularly called a "mold" on bread and other foods. The one which we select for study, as an example, is commonly called the "bread mold"; its scientific name is *Rhizopus nigricans*.

127. Scientific Names.—The necessity for scientific names arises from the fact that different common names are applied to the same sort of plant in different countries, and even in different parts of the same country. The name "bread mold" is not intelligible to a Frenchman who does not happen to understand English; nor is it very exact even in our country, for several different "molds" are common on bread. Scientific names are constructed as follows: Every distinguishable kind of plant that can maintain its identity by reproduction is known as a *species*.[1] Many species, though distinct, resemble each other closely, and are grouped together as a *genus*. The particular bread mold which is discussed in this chapter belongs to the genus *Rhizopus*, together with several other very similar kinds of mold. The species which we are studying is designated by the adjective added to the genus name—*nigricans*. Other species are *Rhizopus oryzae* and *Rhizopus ramosus*. All plants and animals are named in this way. All maples, for instance, are placed in the genus *Acer*. The different kinds of maples are different species—*Acer saccharum*, *Acer rubrum* and so forth. A species may be further divided into races or varieties. This is particularly true of cultivated plants. For example there are more than 60 varieties of oats, all of which belong to the species *Avena sativa*. Each of these is considered a variety and not a species because they can be perpetuated only under cultivation and would merge with one another and disappear in nature.

128. Morphology.—If we examine carefully a *Rhizopus* plant we find that it is composed entirely of threads, which we call *hyphae*, together making up a branched web which we term a *mycelium* (plural *mycelia*).[2] At places on the mycelium small spheres, at

[1] This definition of species is the one commonly accepted by those interested in the classification of living organisms. Other definitions are used by those interested in other phases of biology.

[2] These terms are applied to many fungi, and only to fungi. See the chapter on fungi.

first white and later black, are supported by short upright hyphae. These spheres contain spores, and are therefore called *sporangia* (singular, *sporangium*) or spore sacs, and the hyphae which bear them are *sporangiophores* (spore-sac-bearers). At the base of each sporangiophore is a number of short branching hyphae which penetrate the material upon which the mold is growing. These

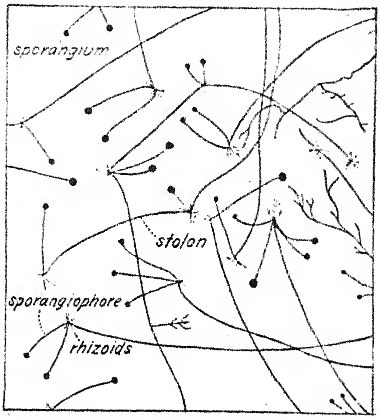


FIG. 142. Diagram of hyphae of *Rhizopus nigricans* showing the parts of the mycelium.

hyphae are called *rhizoids*. Other hyphae extend from the base of the sporangiophores in various directions through and above the substrate. Some of the aërial hyphae where they again touch the substrate bear new clusters of rhizoids and sporangiophores. These hyphae are stolon-like, resembling in their spreading the stolons of such plants as the strawberry (see Fig. 299). Such stolon-like hyphae are present only in a few kinds of fungi.

The contents of the various hyphae are alike—protoplasm containing various small particles of surplus food (usually fat), and vacuoles. The whole plant, as seen in the living condition through the microscope, seems one large cell, indefinitely branched, with few or no cross-walls in the hyphae. If, however, a properly killed and stained mycelium is studied, many nuclei, very small and previously quite invisible, become evident. Each nucleus, with its surrounding cytoplasm, is a center of life activities, just as it would be if there were membranes or walls separating the mycelium into distinct units, each with one nucleus. It is proper, therefore, to regard such a body as in reality composed of many

cells, but of cells not separated by distinct membranes. Occasionally there are walls across the hyphae at irregular intervals; these become more numerous as the mycelium becomes older.

FIG. 143. Portion of a hypha of *Rhizopus nigricans*. The black spots are nuclei.

129. Physiology.—Foods in solution are absorbed from the bread or other substrate, through any part of the mycelium which touches the substrate. These foods are frequently first digested by enzymes secreted by the mold—otherwise, of course, such foods as starch, the chief food in bread, could not be used by the mold. Having been absorbed, the foods are broken down in respiration exactly as in green plants. Other things also are absorbed from the substrate, such as salts containing nitrogen, phosphorus, and the other elements necessary for the continued life of protoplasm. As a result of reaction of these substances and of the foods absorbed, new protoplasm, new walls are built, new cells formed, and the mycelium grows.

Mold is, of course, like the bacteria, a factor to be considered in the keeping and storing of our own foods. Bread or fruit used by *Rhizopus* or any of its relatives becomes unfit for human use just as when it is "decayed" by bacteria. Fortunately, most molds are aërobic—they require free oxygen for respiration; if a food is kept air-tight, it will not mold, even though all the mold spores may not have been killed in preparing the food. This is one of the advantages of coating jellies and jams with layers of paraffin. This serves also, of course, to exclude the mold spores and bacteria of the air. Molds are noteworthy because some kinds will grow in extremely acid substances, and in substances concentrated to a degree which would cause plasmolysis and finally death in other plants.

130. Reproduction.—The small knobs (sporangia) at the ends of the sporangiophores, which have been described above, are at first simply the swollen ends of these hyphae. There is a streaming of cytoplasm and nuclei into these knobs. Then a wall (the *columella* wall) is formed which separates the rounded terminal portion from the part next to the stalk, the wall being dome-shaped, so that the hypha seems to project up into the knob.

Walls are then formed throughout the protoplasm,[3] separating it into small masses. These are not cells, however, for each contains usually several nuclei and is therefore a group of cells not separated

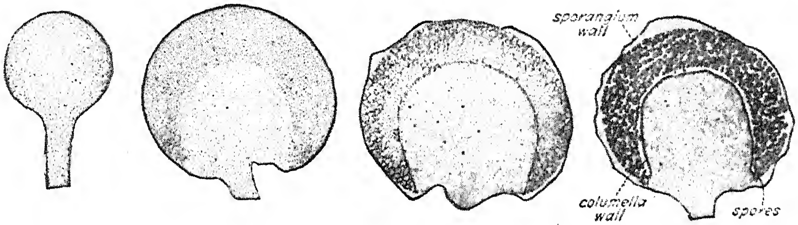


FIG. 144. Longitudinal sections through developing sporangia of *Rhizopus nigricans*. The small black dots are nuclei. (From Swingle, Bureau of Plant Industry Bulletin 37.)

from one another. The wall of each little mass of protoplasm becomes dark-colored (and thus the entire knob comes to appear black) and fairly resistant to drying. Finally the outer wall of the sporangium, which encloses all these bodies, is broken[4] and the latter are scattered into the air. They may live a considerable time in the air, since they possess stored food and are encased by a fairly thick wall. If one is deposited on food (moisture also being

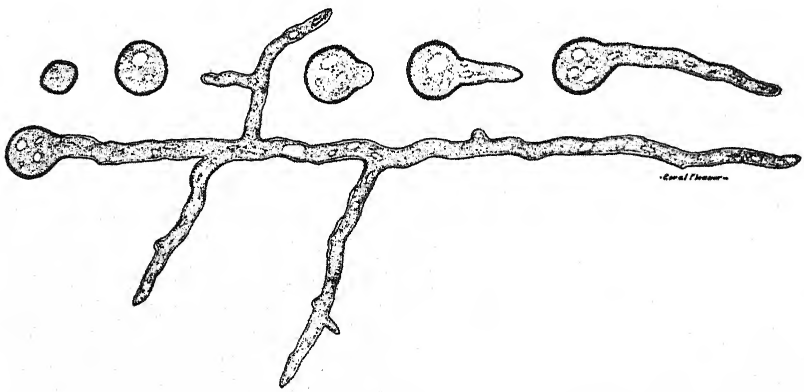


FIG. 145. Series of figures to show spore germination of *Rhizopus nigricans*.

[3] The walls are formed by a peculiar process known as "furrowing." Vacuoles in the cytoplasm lengthen and merge with each other, forming furrows or grooves which divide the cytoplasm into many separate bodies. The columella wall is formed in the same way.

[4] Usually if one places it in water it breaks immediately.

present) it may germinate and form a hypha and from this an entire new mycelium similar to the one from which it came. These bodies are therefore called spores—like those of the bacteria they are capable of growth; they differ only in being small groups of cells instead of single cells.

Rhizopus produces sporangia by the thousands—and each sporangium forms a hundred or more spores. It is because of the presence of these spores in the air that mold develops on any food which is suitable for its growth and exposed to the air. One cannot wonder at the older idea of its "spontaneous" origin.

Besides forming spores, *Rhizopus* reproduces by another method. When certain mycelia come in contact, short swollen hyphae are formed, one from one mycelium touching one from the other. Each of these hyphae becomes divided by a cross wall into a basal and a terminal part; and the wall between the two terminal parts disappears, so that the two bits of protoplasm become one. Bits

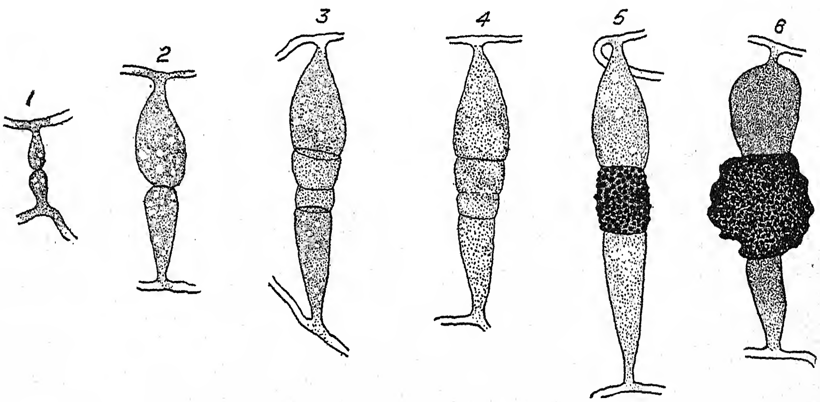


FIG. 146. The formation of the zygote by *Rhizopus nigricans*. *1*, *2*, Progametes are formed by the "plus" and "minus" strains; *3*, each progamete divides into gamete and suspensor; *4*, wall separating gametes disappears; *5*, *6*, the zygote is formed. The "plus" strain develops the larger gametes and suspensors.

of protoplasm (in most plants single cells, but here groups of cells) that unite in this way and form a body capable of development are known as *gametes*. The product of their union is a *zygote*. They are found in many plants besides *Rhizopus*, and, as we shall see, are formed in many different ways. The original short hyphae which by division form the gametes of *Rhizopus* are called the

progametes; each progamete divides into a gamete and a basal portion known as a *suspensor.* The zygote forms about itself an exceedingly heavy, black, rough wall; and contains an abundance of stored food (fat globules). Because of these characteristics it can remain alive for a long time after the food and water of the substrate have been exhausted. Under certain conditions the wall cracks open, and the contents project, in the form of a hypha

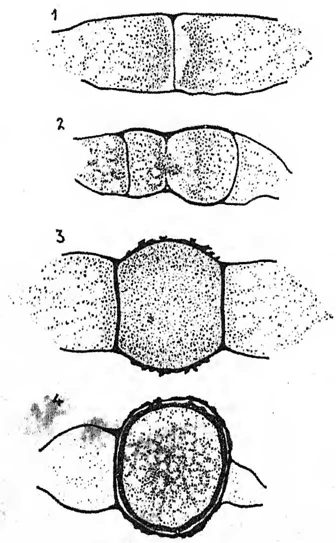


FIG. 147. Sections through progametes, gametes and zygotes of *Rhizopus nigricans.* The larger black dots are nuclei. (After Keene from Gaümann, *Vergleichende Morphologie der Pilze*, Gustav Fischer, Jena.)

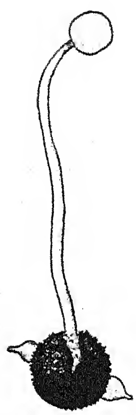


FIG. 148. A germinated zygote (dwarf mycelium) of *Mucor mucedo*, a mold closely related to *Rhizopus.* (Redrawn from Strasburger, Noll, Schenck and Schimper, *Lehrbuch der Botanik*, Gustav Fischer, Jena.)

(a zygote is therefore a kind of spore—formed in a special way); on the end of the hypha is formed a sporangium. The spores formed in this sporangium develop under suitable conditions into ordinary mycelia.

Not any two mycelia will form gametes which unite with each other. There are two sorts of mycelia, and one of one kind must be in contact with one of the other before any formation or union of gametes will take place. These two sorts are structurally alike,

but one grows more vigorously than the other, and for this reason the two sorts are distinguished by the names of "plus" and "minus" strains. In other plants, as we shall see later, and in animals, there are frequently more marked differences between gametes and the individuals which produce them, and they receive other distinguishing names.

A third method by which *Rhizopus* may be reproduced is by the breaking or fragmentation of its mycelium. If a piece of the mycelium is torn loose and transferred to a suitable nutrient medium, it will grow into a new and complete *Rhizopus* plant.

131. **Life History or Life Cycle.**—*Rhizopus* thus reproduces in several different ways. Moreover, it exists in several different forms. The zygote is of course just as much a *Rhizopus* plant as the mycelium itself; so is the dwarf mycelium—consisting usually

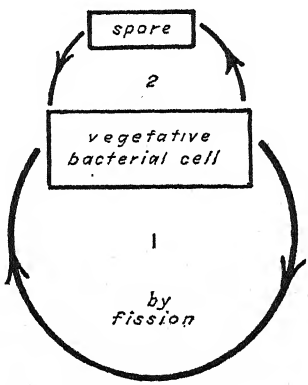


FIG. 149. Diagram of the life-cycle of the bacteria.

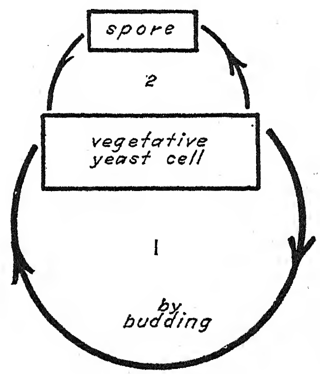


FIG. 150. Diagram of the life cycle of the yeasts.

of one hypha and a sporangium—to which it gives rise. When we speak of a "*Rhizopus* plant" we commonly mean a growing, *vegetative* plant—the mycelium; but we must not lose sight of the fact that we might just as well mean a *Rhizopus* spore, or a *Rhizopus* zygote, or the plant that results from the germination of a *Rhizopus* zygote. Furthermore, these different forms of the plant follow each other in a definite order. A mycelium usually forms spores, and the spores may become new mycelia; two mycelia may form gametes, and the result is a zygote; later the zygote may become a dwarf mycelium. These facts form what we call the *life cycle*,

or *life history*, of *Rhizopus*. A life cycle or life history is simply an enumeration in their natural order of all the different sorts of *individuals*, produced by reproduction, of any one *kind of plant*.

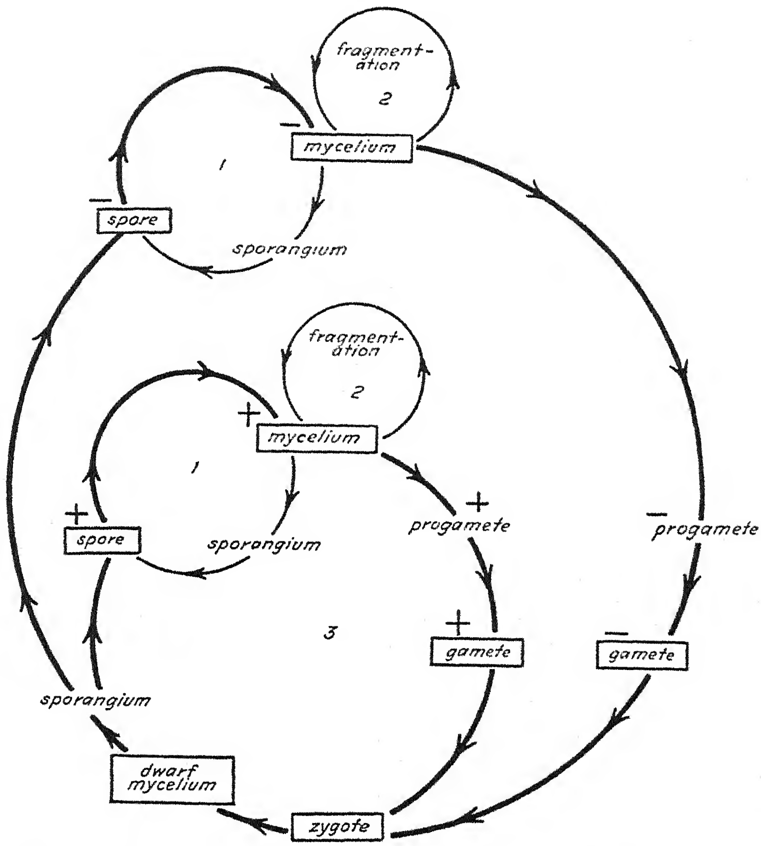


FIG. 151. Diagram of the life-cycle of *Rhizopus nigricans*.

This may be conveniently expressed by a diagram, as is shown in the accompanying figure. The life cycle of bacteria or the yeasts may be completed in two different ways; that of *Rhizopus* in three ways.

CHAPTER XVI

Reproduction

It is apparent, even from the few plants we have now studied, that reproduction is not a simple process. It is rather the name of a group of processes; the only thing common to all of them being the result.

The formation of new individuals is, of course, directly or indirectly dependent upon the formation of new cells, since all individuals are composed of cells. When a one-celled organism divides, the result is called reproduction, since the daughter cells are themselves new individuals, independent of each other for continued existence. When the cells of a many-celled organism divide, the daughter cells usually become specialized and dependent upon one another; they are not separate individuals but together compose one individual. For the cells the result is reproduction (new cells are formed); for the individual it is not reproduction, but growth. Certain particular cell divisions, however, may result in the formation of certain particular cells or groups of cells (spores or gametes) which become new individuals. And sometimes, under special circumstances, vegetative cells (that is, cells other than spores or gametes) may become new individuals, through what is called vegetative reproduction.

132. **By Spores.**—Both one-celled and many-celled plants reproduce by means of *spores*. A spore is a small mass of protoplasm, commonly a single cell but sometimes a group of cells; it usually differs in structure from other cells of the plant; it is not especially fitted for vegetative functions, but is more or less limited to a reproductive function and undergoes considerable modifications in structure when it assumes the vegetative functions. In the plants we have studied the spores are resistant bodies, but this is not necessarily true. Spores are of various sizes, shapes, and properties, in different plants. And they may be formed in very different ways. We have studied endospores—spores formed within single cells; and spores formed in sporangia. Other kinds will be described later.

133. By Gametes.—Most plants and animals form that special sort of spore known as a zygote, which originates from the union of two masses of protoplasm known as gametes. This may be

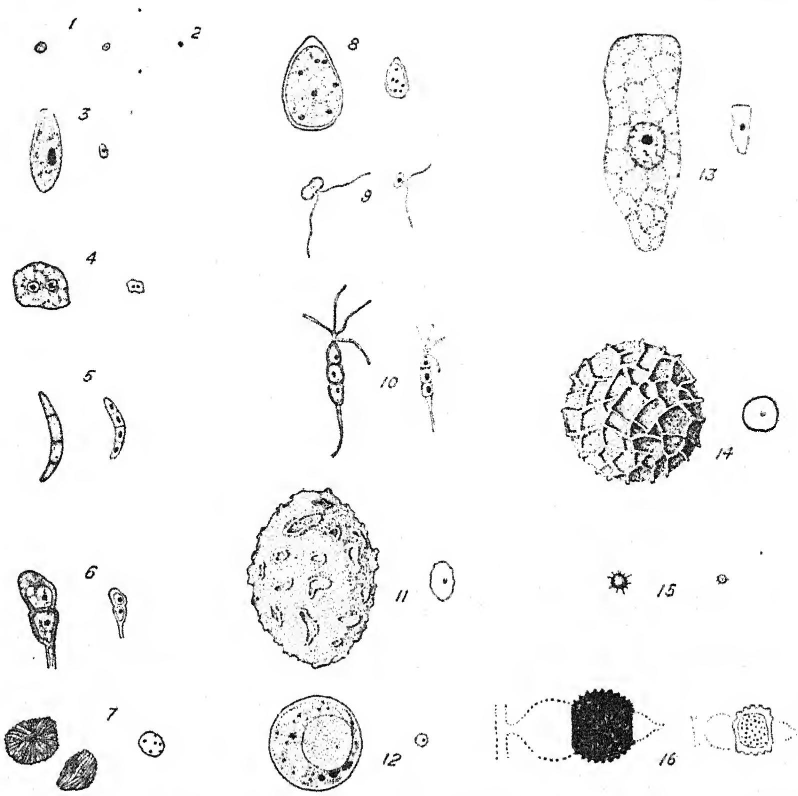


FIG. 152. Various kinds of spores. The nuclear condition is shown by the diagram to the right of each spore. *1*, conidium of *Penicillium; 2*, bacterial endospore; *3*, conidium of *Erysiphe; 4*, aeciospore of *Puccinia graminis; 5*, spore of *Fusarium; 6*, teliospore of *Puccinia graminis; 7*, spores of *Rhizopus; 8*, conidium of *Phytophthora infestans; 9*, swarm spore of *Phytophthora infestans; 10*, spore of *Pestallozia; 11*, fern spore; *12*, moss spore; *13*, megaspore of corn; *14*, megaspore of *Selaginella; 15*, microspore of *Selaginella; 16*, zygote of *Rhizopus*. 1 to 10 ×500, 11 to 16 ×50.

termed *gametic* reproduction or *syngamy*. It is often also called *sexual* reproduction, especially in animals. But the structures and activities of animals and plants are so different that it is wisest not to use the same terms for both until they are very well understood.

134. Vegetative Reproduction or Reproduction by Fragmentation.—Vegetative parts of many plants will if broken off continue to grow and often form the missing parts. This is true of *Rhizopus.* If a piece of the mycelium is separated from the rest, and placed in a suitable environment, it will grow and form a complete mycelium, with rhizoids, sporangia, and all its other parts. This is true also, as we shall see later, of many other plants; and the fact is used in horticulture and agriculture, as in the propagation of many plants by means of "cuttings" or "slips." The difference between this form of reproduction, which is called *vegetative* reproduction or reproduction by *fragmentation*, and spore reproduction is that in the latter only a single cell or a very small group of cells is concerned in the starting of the new growth, and this cell (or group of cells) is more or less specialized and does not perform most of the ordinary vegetative functions while a part of the parent organism; while in vegetative reproduction the cells concerned are usually many, are not specialized for reproduction, and form an actively vegetative part of the parent organism until separated from it.

Vegetative reproduction illustrates well the essential distinction between reproduction and growth. The activities which occur during reproduction—the formation of new cells, enlargement and differentiation of cells—are the same as those which occur during growth. The result only is different. If the new cells formed continue to form a part of the original individual and do not live independently of it and of each other, we call the process growth. If the new cells become new individuals, each possessing the parts characteristic of a complete plant of that species, we call the process reproduction.

135. Other Methods of Reproduction.—The cell division of single-celled organisms, for example the fission of bacteria and budding of the yeasts, is a method of reproduction. The new cell formed is a complete individual and no missing parts need be regenerated. In this respect fission or budding is different from reproduction by fragmentation. The new cell is not a spore and no cell fusions are concerned in its formation. All those methods of reproduction which do not involve cell fusions are known as agametic or asexual. Reproduction by spores, by fragmentation, by fission, and by budding are agametic types of reproduction. Mention should also be made of reproduction by seeds, a method limited to the seed plants and one which includes both reproduction

by spores and reproduction by gametes. It is described more at length in the discussion of the reproduction of the seed plants.

136. **Constancy of Type in Reproduction.**—One of the remarkable facts about reproduction is that the bit of protoplasm, whether spore, gamete, or anything else, that develops into the new plant, always grows and reacts to its environment in the way characteristic for that sort of plant. The spore of *Rhizopus* always grows (if it develops at all) into the parts characteristic of a *Rhizopus* plant, never into those of a yeast or a sunflower. The spore of the anthrax bacillus never becomes a tuberculosis bacillus or any kind but an anthrax bacillus. The protoplasm never seems to "lose its way." This does not mean that the new plant is always like the old one. A corn seedling, if grown in the dark, is an elongated, flabby, white plant quite unlike its parent—but it is what its parent would be under like conditions. The new plant behaves in a way characteristic of corn plants. Furthermore we have seen that the product of gametic reproduction in *Rhizopus* is a plant—the zygote—quite different in size, shape, and activities from either of its parents. It is spherical, very thick-walled, black, while the parents were filamentous, much branched mycelia. Furthermore the zygote, when it does grow, forms a dwarf mycelium, consisting of a few hyphae only, with one or few sporangia. But this plant, though unlike the parents, is quite characteristic for this particular kind of mold, and may be expected when two *Rhizopus* gametes unite.

The offspring of a given type of plant always behaves in a way and is of a form characteristic of that type of plant. Though it may not resemble its immediate parent or parents, it does resemble other and more distant progenitors which originated by the same method of reproduction as it did; all observed plants which have resulted from the growth under similar conditions of zygotes of some particular kind of plant resemble each other in structure and behavior, though they very commonly do not resemble their immediate parents. Hence the life cycle of any one type of plant is an orderly series usually of differently constructed individuals following each other always in the same sequence. Why the offspring should not exactly resemble the parent, even though both grow in the same environment, we do not yet completely know. We have seen in our study of cell division (which is the fundamental basis of all plant growth and reproduction) that the

daughter cells possess living substances, namely cytoplasm and chromatin, which were parts of the mother cell. The nature of this protoplasm apparently remains fundamentally unchanged from generation to generation and reproduces the same cycle of forms over and over again. The exact form of the individuals is influenced by the environment (as in the example of the corn plant mentioned above), and by other unknown factors, which determine whether it grows (for instance) into an ordinary *Rhizopus* mycelium or into a dwarf *Rhizopus* mycelium. Whatever the form of the mature individual, *Rhizopus* protoplasm remains *Rhizopus* protoplasm. The small portion of this protoplasm which constitutes the beginning of a new individual (a spore or a gamete or a bit of vegetative mycelium) is the *biologic inheritance*[1] of that individual from its parent. The offspring does not "inherit the characters of its parent," as is so frequently stated: it inherits a little bit of protoplasm, one or a few cells, which in its development assumes certain characters, according to the type of protoplasm.[2] This protoplasm, for example that in a living *Rhizopus* spore, might be called the protoplasmic bridge from the parent mycelium which produced the spore to the new mycelium which grew from it.

137. **Reproduction and Immortality.**—And this in turn leads us to the interesting reflection that protoplasm is, at least potentially, immortal. The protoplasm of a bacterium is the same protoplasm,[3] or a part of it, as that of the first bacterium of that kind that ever existed. The protoplasm of a *Rhizopus* plant was once contained in a spore, which was part of a previous *Rhizopus* plant; and so on, back through the ages. The old Adam is in us yet!

Immortality has therefore a meaning here on earth. Of course protoplasm does die—is continually dying; but *some*—it may be a very small part of the whole organism—always remains and is the beginning of new individuals.

Living protoplasm may be compared to the flame of a gas burner. Such a flame has a certain structure of its own, has certain colors, radiates a certain amount of heat, and so forth. Yet the actual chemical molecules of which the flame is composed

[1] Other kinds of inheritance involve land, money, education, and the like, external to the living body.

[2] See the chapter on the Formation of New Cells.

[3] In the sense that there has been no break in its continuity. Its structure has been continuously maintained, though of course its molecules are continually being lost and replaced by new ones.

are hardly the same for two moments together; there is a continuous intake and outgo of chemical substances, a continuous chemical reaction. So with protoplasm—it keeps its individuality, keeps on "burning," as long as environmental conditions permit; and this though it becomes infinitely subdivided into millions of packages—cells.

CHAPTER XVII

The Fungi

Bacteria, yeasts, and *Rhizopus* have several things in common. They all lack chlorophyll. And, though they are differentiated in various ways, none of them have leaves, stems or roots. Plants (and animals) are grouped for purposes of convenience according to similarities in their structure and activities. Thus we group together all the plants that lack stems, roots, and leaves, and name the group *Thallophytes*. We designate the type of plant body that has no leaves, stems, or roots a *thallus* (plural, *thalli*); and the termination "phyte" means plant; therefore Thallophytes means "thallus-plants." Among the Thallophytes we find many differences: some, for instance, have chlorophyll; while others, as we have seen, have none. The latter group is known as the *fungi;* any one of them is a *fungus*. The former (to be studied later) is the *algae* (singular, *alga*). Within these groups, in turn, many smaller groups can be made, based on similarities. Usually we group plants together on the basis of similarities in methods of reproduction, because this character is the one that seems most constant for any one plant. It must be emphasized that classification is a matter of convenience. When we wish to speak of these plants with no leaves, stems, and roots and no chlorophyll, it is simpler to speak of the fungi than to enumerate by name all the different plants of this kind we know. The present scheme of classification is not necessarily the only possible one or the best. It may be changed in the future just as it has been in the past. In the natural system of classification we arrange the groups to include plants supposedly naturally related to each other; but this is a point very difficult to determine, and plants included in one group are not necessarily related.

The bacteria are so different, both in their structure and in their activities, from all other plants that they are sometimes placed in a group by themselves. It is simpler, however, to regard them as one of the divisions of the fungi, separated from the others by their very simple cell structure and minute size, and by their

methods of reproduction. Because they reproduce by fission they are frequently called the fission fungi or *Schizomycetes*.

Phycomycetes

Rhizopus differs markedly from the bacteria both in structure and in methods of reproduction. There are many other fungi more or less resembling *Rhizopus* in these respects. All of them have filamentous multinucleate bodies with few or no cross walls (are *coenocytic*) and all of them reproduce gametically. These fungi are called *Phycomycetes*, which means alga-like fungi—so-called because their coenocytic bodies and methods of gametic reproduction are similar to those of certain algae.

138. Empusa.—Many of the Phycomycetes secure their food as *Rhizopus* does from non-living material; they are saprophytic. Some of the members of this group are parasitic, deriving food from the bodies of living organisms. One of these is *Empusa*, which infects insects. The spore germinates on the body of a fly, and the hypha penetrates the tissues of the latter, and becomes a mycelium, which causes a diseased condition of the fly, usually

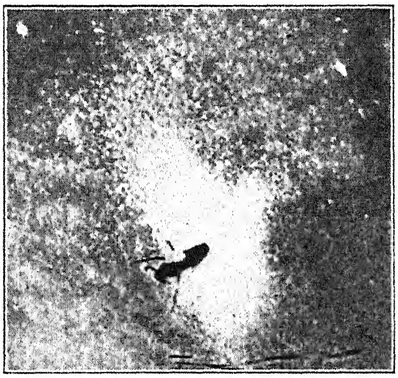


Fig. 153. A fly killed by *Empusa muscae*. Spores of *Empusa* form the white area around the fly. (From Buller's *Researches on Fungi*, Longmans & Co.)

ending in death. Union of gametes occurs; and spores are formed—not in sporangia, as in *Rhizopus*, but formed simply one at a time by cell division of the end of a hypha (spores formed in this way are known as *conidia;* singular, *conidium*). You may have seen at some time on a window pane a dead fly surrounded by a

halo of whitish dust. The dust probably consisted of the conidia of *Empusa*.

Thus other fungi besides bacteria may be the cause of diseases. The above is a disease of insects and the fungus *Empusa* is the cause of it. Many kinds of fungi infect plants. The diseases which they cause are just as serious to the plant or animal infected as ours are to us; and indirectly they are very important to us also, for they may cause the failure of crops upon which the life of man depends. The immense importance of a single plant disease, caused by a Phycomycete, is illustrated by the history of the great Irish famine of 1845.[1]

139. Phytophthora infestans and Potato Blight.—The white potato (*Solanum tuberosum*) seems to have been cultivated in some parts of South America by the natives since prehistoric times. The first European explorers found these plants in cultivation in the temperate parts of the Andes. According to the Spanish, potato plants were found in 1550 near Quito in Ecuador. Potato tubers were brought from Peru and Chile in the sixteenth century to Europe and were introduced into England in 1586 and grown there. Later the potato was taken to Spain and soon its cultivation extended to Italy, Austria, France, Switzerland, and Germany. It was first grown as a botanical curiosity in botanical gardens. During the seventeenth century it was cultivated in gardens and fields. The cultivation of the potato became general in Europe and North America in the eighteenth century. After two hundred and fifty years of culture as a curiosity and more than one hundred and fifty years of general culture in England and North America the appearance of a disease, now called late blight or downy mildew, was recorded. By 1835 it was so bad in England that the Scottish Agricultural Society offered (in 1837) a prize for the best cure. In 1840 in Bavaria, Germany, the disease destroyed two-thirds of the crop, and in 1842 at several places along the Rhine one-half of the crop was destroyed. The climax was reached in 1845. In that year four per cent of the cultivated land in Ireland was planted to potatoes. The whole crop failed. Father Matthew (as quoted by Rolfe) wrote: "On July 27 I passed from Cork to Dublin and the doomed plant bloomed in all the luxuriance of an abundant harvest. Returning on August 3, I beheld with sorrow mere

[1] The following account is taken in the main from Erikson. Archiv. f. Bot. **14**: 1–71.

wastes of putrefying vegetation." Two hundred and fifty thousand people or one-thirty-second of the whole population of Ireland died from starvation and resulting sickness, in spite of private assistance of all descriptions. In addition many thousands of the Irish people emigrated, chiefly to the United States.

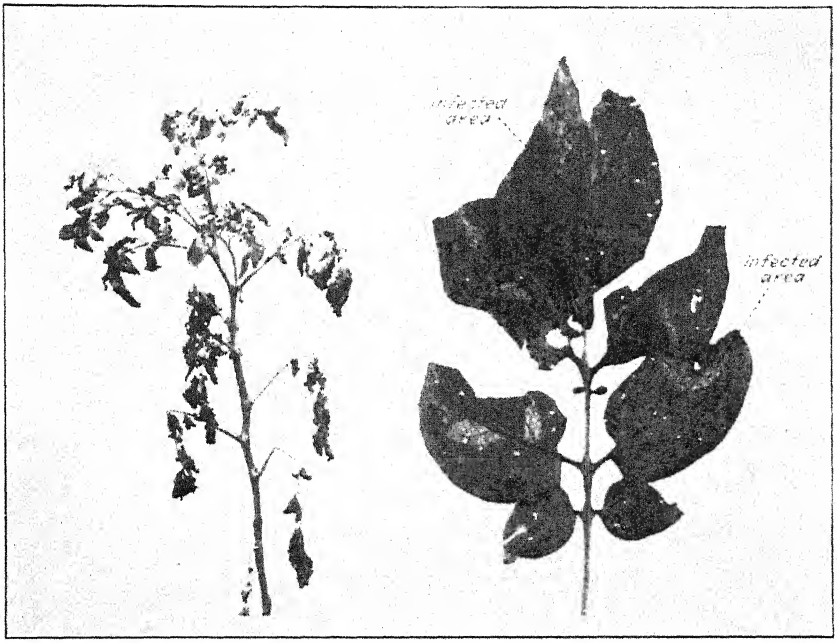


FIG. 154. Left, a potato plant affected with late blight; right, potato leaves showing infected areas. (From New York Agricultural Experiment Station, Geneva, Bulletin 241.)

The cause of this disease is a Phycomycete, *Phytophthora infestans*. The mycelium—coenocytic like that of *Rhizopus*—grows in the tissues of the potato plant, chiefly between the cells, though short hyphae may grow into the cells of the host. The mycelium produces and excretes a toxin which kills the cells of the potato plant, and the contents of these dead cells diffusing out into the intercellular spaces are used by the mycelium as food. Thus the leaves, stem and tubers of an infected potato plant may contain dead areas. Hyphae grow out through the stomata, especially those of the lower epidermis of the potato leaves, and form conidia,

which drop off and are carried by the wind or insects to healthy leaves. If a film of water is present where it falls each conidium may swell and produce a short hypha which penetrates the potato

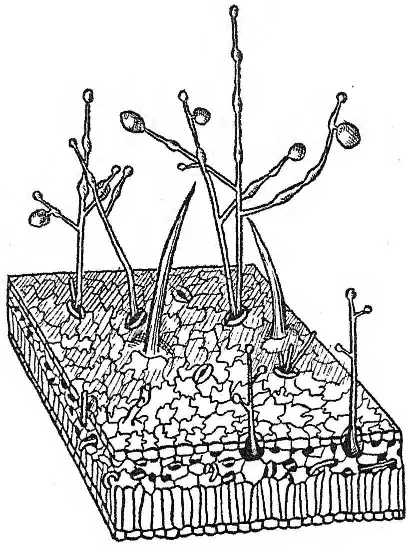


Fig. 155. Portion of a potato leaf showing conidiophores and conidia of *Phytophthora infestans*. (Redrawn from Vermont Agricultural Experiment Station Bulletin 168.)

plant. Or the contents of the conidium may separate into several bits of protoplasm each with a nucleus and two flagella. The cracking of the conidium wall permits these minute bits of protoplasm to escape and swim away. These are called *swarm spores* or *zoöspores*. They eventually lose their motility, round up, and form a hypha which penetrates the tissues of the host. Once the hypha, either that from the conidium or from the swarm spore, has entered the potato plant it grows into a much branched mycelium which again produces conidia. The growth from conidium to conidium under favorable circumstances may require only a few hours; in moist cool weather the disease may spread very rapidly.

Besides conidia *Phytophthora infestans* has been observed, though infrequently, to produce gametes and zygotes. The two gametes which unite to form a zygote are, however, not of the

same size and the zygote (usually called an *oöspore*) forms swarm spores instead of forming a hypha and a sporangium as that of *Rhizopus* does.

A potato plant once attacked by *Phytophthora infestans* cannot be cured; but since new plants are infected by conidia which

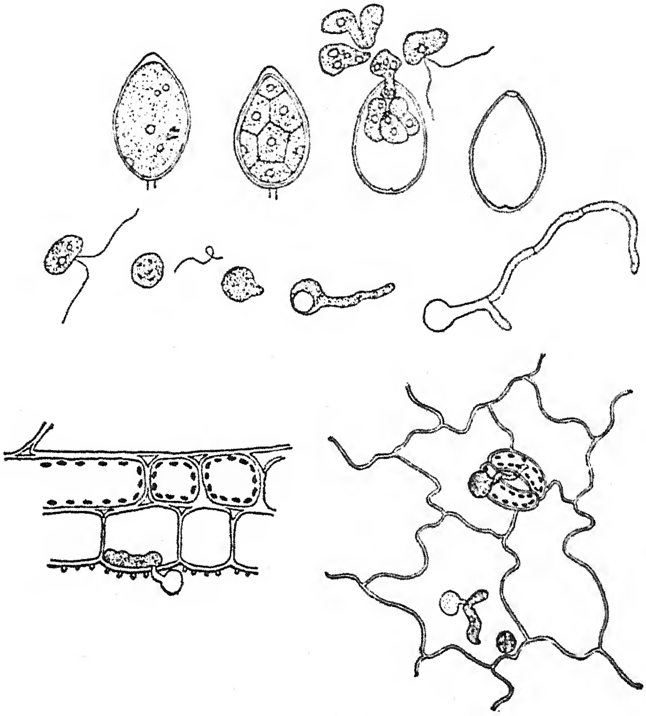


Fig. 156. Above, conidium of *Phytophthora infestans* forming swarm spores and the swarm spores germinating; below, hyphae from germinating swarm spores penetrating the potato leaf. (After Ward, in the Quarterly Journal of Microscopical Science.)

alight on the surface of the plant, the disease can be checked by spraying the healthy plants with a solution that is poisonous to conidia and swarm spores. Such a solution is Bordeaux mixture, which contains copper sulfate. The use of such a spray from three to seven times a season in regions where the disease is prevalent has proved an effective preventive.

Had the life history of *Phytophthora infestans* and the use of

Bordeaux mixture been known in 1845, the Irish famine and all its attendant suffering need never have occurred. It required almost fifty years of painstaking work by many trained men to accumulate

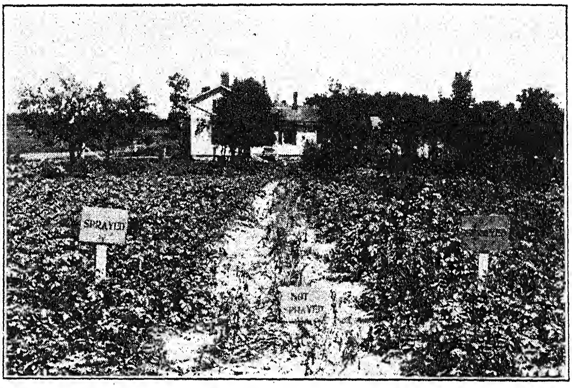


FIG. 157. The effect of spraying with Bordeaux mixture in preventing potato blight. Gain due to spraying, 156 bushels per acre. (From New York Agricultural Experiment Station, Geneva, Bulletin 264.)

sufficient knowledge of the disease, of its cause, and finally of its control to make the recurrence of such an affair unnecessary.

Ascomycetes

A large number of fungi are characterized by the formation of sporangia of a special type called *asci* (singular, *ascus*). An ascus contains a definite number of spores (*ascospores*), usually four or eight, which are formed by a peculiar method of cell division. The peculiarity lies in the fact that not all the cytoplasm of the parent cell enters into the formation of the new cells; much of it remains in the ascus outside of the spores, and ultimately dies. The fungi which form asci vary immensely in vegetative characteristics, in sources of food, and in other methods of reproduction; but their asci are remarkably constant structures, which enable us to group them all under the name of ascus fungi, or *Ascomycetes.* The yeast is frequently classified as an Ascomycete, the yeast cell with its endospores being considered an ascus.

140. Exoascus deformans and Peach Leaf Curl.—Many of the Ascomycetes cause plant diseases, some of them of great economic importance. A common disease of peach trees, known as leaf curl,

is caused by an Ascomycete named *Exoascus deformans*. The body of this fungus is a mycelium, which differs from that of *Rhizopus* and other Phycomycetes in that its cells are separated by definite walls. It grows between the cells of the host, causing

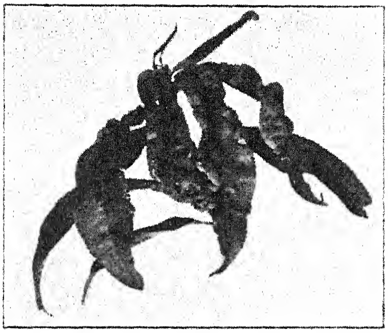


FIG. 158. Peach leaf curl, caused by a fungus, *Exoascus deformans*.

a discoloration and curling of the leaves, enlargements of the young stems, and finally perhaps the fall of the leaves. Cells of the mycelium next to the epidermis of the host push up, breaking the epidermis, and become asci, each of which contains at maturity eight ascospores. These ascospores may bud somewhat as yeast cells bud, producing new spores which are called conidia. The conidia, or the ascospores, may be carried to new hosts and there grow into new mycelia, which penetrate the tissues of the hosts.

141. **Powdery Mildews.**—On the leaves of many plants such as red clover, lilac and the rambler roses you may have noticed a grayish coating which looks much like a film of dried soap suds. Microscopic examination shows this to be the branching hyphae of a fungus which spreads over the surface of the leaf. The hyphae are not coenocytic. Each nucleus and surrounding cytoplasm is separated from the neighboring nuclei and cytoplasm by a cross wall, so that a single hypha is composed of cylindrical cells arranged end to end. Short hyphae can be found which extend down into the tissues of the leaf upon which the fungus grows. These are called *haustoria* (singular, *haustorium*). They absorb from the host the water, mineral salts, and food material which the fungus uses in growth. The fungus on lilac is named *Microsphaera alni*, that on red clover is *Erysiphe polygoni*, that on the rambler rose is

Sphaerotheca pannosa. Each of these species can infect only certain kinds of host plants. Rising vertically from the surface mycelium and pointing away from the leaf are short hyphae which bear conidia. Each conidium consists of a cell wall surrounding a minute bit of protoplasm containing a single nucleus. The conidia readily break apart from one another and, being microscopic in size, can be carried by air currents to other plants, where, if there

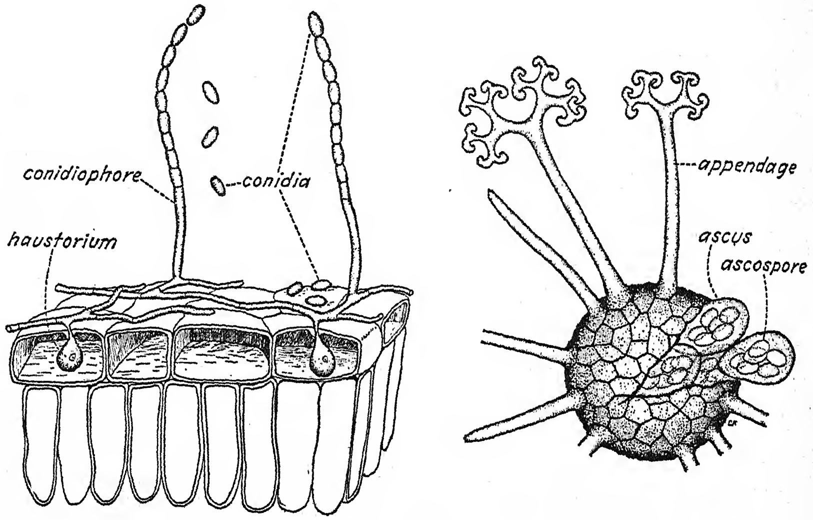


FIG. 159. Left, portion of a leaf infected with a powdery mildew; right, perithecium of *Microsphaera alni* cracked open, showing asci and ascospores.

is a film of water, they may germinate into a mycelium, which produces haustoria and conidia in turn and so repeats the cycle on a new host. The number of conidia formed is so great that a blow on a branch having leaves covered with the fungus may dislodge enough of them to be visible as a dust cloud. This group of fungi is therefore commonly called the Powdery Mildews.

In the fall black spots each smaller than the point of a lead pencil may frequently be observed on the mycelium of a powdery mildew. Microscopic examination shows these to be black spheres (*perithecia*) with hyphae (*appendages*) extending out like the spokes of a wheel. If the perithecium is broken open it is found to contain one or several thin-walled sacs, and, lying free from one another within each sac, are from two to eight uninucleate ellipsoidal cells

each of which is capable of growing into a new mycelium and is evidently a spore. These sacs are asci, the spores are ascospores. Each ascus results from gametic reproduction in this way: Certain cells of the mycelium unite, and may therefore be called gametes. The zygote, however, is not a resting cell, nor does it become detached from the rest of the mycelium. It devel ps into a hypha or group of hyphae, some cells of which become sacs containing spores. At the same time as this is happening a dense mass of hyphae from the parent mycelium grows up around each ascus, or around a group of them, so as finally to enclose them completely. This mass becomes a hard black body, the perithecium. When the rest of the mycelium dies, the perithecium and its contents continue to live, because of the protection afforded by the heavy perithecial wall. It is probably in this form that the powdery mildews live over the winter, for they can grow on nothing but

FIG. 160. Sporophores of *Morchella*.

living plants. They are not only parasites; they are *obligate parasites*. When subjected to moisture, the perithecium cracks open, releasing the ascus or asci inside; the latter in turn rupture

and release the ascospores; which may develop into new mycelia if they come into contact with the proper sort of host.

142. Other Ascomycetes.—The common "black molds" and "green molds" (*Aspergillus*, *Penicillium*) are Ascomycetes; they reproduce also by conidia. The "cup fungus" often found in the woods, growing in damp leaf mold, is an Ascomycete. In this plant the hyphae do not remain discrete threads but become associated together and form a fleshy cup, the interior of which—at first a rich scarlet, later black—is lined with asci. Still another kind, *Morchella* (commonly called the morel), has a large stalk supporting a head covered with an irregular network of ridges. The asci are formed in the depressions between the ridges. *Mor-*

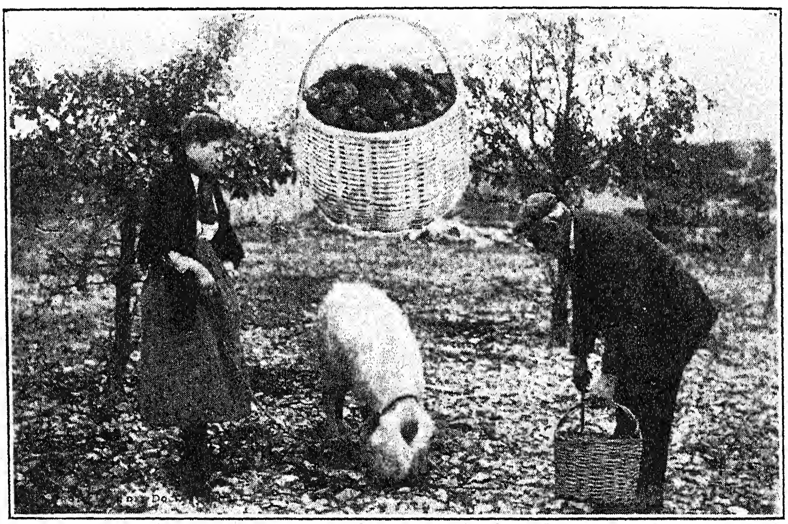


FIG. 161. Hunting truffles. (Courtesy of Païta, Guérin et Jougla, Cahors, France.)

chella is an edible fungus of a pleasant flavor. A curious fungus is the so-called truffle, also edible and highly prized as a delicacy. Truffles are reproductive bodies comparable to perithecia, but fleshy and solid, and produced underground from a saprophytic mycelium living in the soil in deciduous woods. They are gathered for food by men who make a livelihood by selling truffles. As truffles emit a characteristic odor they are located by especially trained dogs or pigs, whose keen sense of smell enables them to locate them under the ground. The labels on cans in which truffles

are preserved for shipment to all parts of the world often include hunting scenes where the man and his truffle dog figure prominently.

Basidiomycetes

Another group of fungi of very great importance is the *Basidiomycetes*, which are characterized by a reproductive structure called a *basidium* (plural, *basidia*). A basidium is a hypha which produces on its surface several tiny spores, each *basidiospore* being connected with the basidium by a short slender thread called a *sterigma* (plural, *sterigmata*). The number of spores is usually four, but may vary considerably in different kinds of Basidiomycetes.

143. **Puccinia graminis and Wheat Rust.**—One of the most important groups of plant diseases, the rusts, is caused by Basidiomycetes. The rust fungi are obligate parasites which produce red, yellow, or black blotches on the leaves, stems and fruits of other plants. Over two thousand kinds are known and they are very destructive to cereal crops, apples, roses, carnations and many other ornamental or food plants. The fungus (*Puccinia graminis*) which causes the stem rust of wheat will serve as an illustration of this group. It may live on two distinctly different host plants and it may produce five different kinds of spores. If young wheat plants are examined, rust-colored streaks, a few millimeters long and as thick as a needle, may be found running longitudinally on the stem. Each streak is called a *sorus* [2] and contains hundreds of binucleate spores, each borne on a short stalk and each containing an orange-yellow oil. The stalks on which the spores are borne arise from a mycelium which grows among the cells of the stem of the wheat plant under the sorus. This spore is called a *urediniospore*. Being microscopic in size, urediniospores are easily carried from place to place. If they fall where there is water they germinate, each sending out one or more hyphae, which grow out through thin places in the spore wall. There are four of these thin spots equidistant on the equator of the spore. If the urediniospore germinates on another wheat plant the hypha produced may grow into the tissues of the wheat plant and form there a considerable mycelium,[3] which may again produce

[2] The word sorus is used to designate a group of spores. Sori of different plants are of very different types.

[3] The growth of the fungous mycelium within the wheat plant robs it of food and results in the production of stunted grain. In bad rust years the reduction of yield totals millions of dollars.

urediniospores, and so the fungus may spread rapidly through an entire wheat field or from one field to another. The spread is most rapid in cool wet weather. As the wheat plant grows older the mycelium forms thick-walled spores each divided into two parts

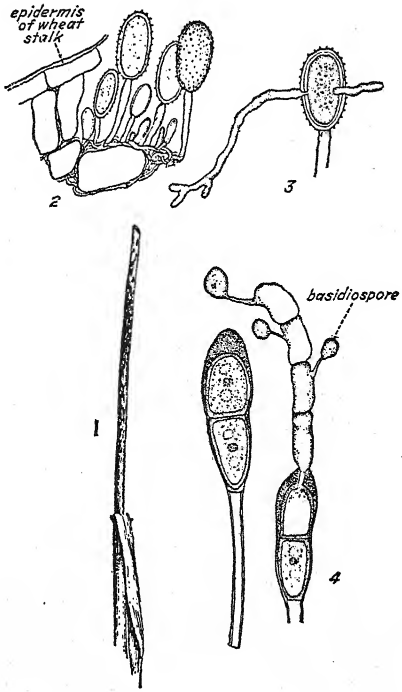


FIG. 162. *Puccinia graminis.* *1*, wheat stalks with sori; *2*, section through a portion of uredinial sorus; *3*, germinating urediniospore; *4*, teliospore and germinating teliospore. (Adapted from Duggar, *Fungous Disease of Plants*, Ginn & Co.)

by a cross wall.[4] These spores also occur in sori but in masses are black. The stem of the wheat plant then has black streaks upon it instead of red ones. These spores are called *teliospores.* The teliospore, because of its thick heavy wall, and perhaps because of the condition of its protoplasm, can live for some months without developing, which the urediniospore cannot do. It is in this condition that *Puccinia graminis* over-winters in the cooler climates.

[4] The teliospore is commonly spoken of as two-celled. Each "cell," however, has two nuclei when the spore is formed; so it is really a four-celled structure. Later the two nuclei in each "cell" fuse, resulting in a truly two-celled spore.

In the spring and in the presence of water the teliospore germinates, producing a short hypha from one or from each cell. Each hypha becomes segmented by cross walls into four cells and from each of these cells a short projection grows out and develops a small, uninucleate spore on the end. This hypha is a basidium, the short projection a sterigma, and each small spore a basidiospore. The basidiospore may germinate and produce a hypha, but this hypha cannot grow in the tissues of the wheat plant. It can grow in those of the native barberry. If therefore the teliospore germinates upon a barberry leaf or if the basidiospores are carried to the barberry leaf, the mycelium of *Puccinia graminis* is soon growing

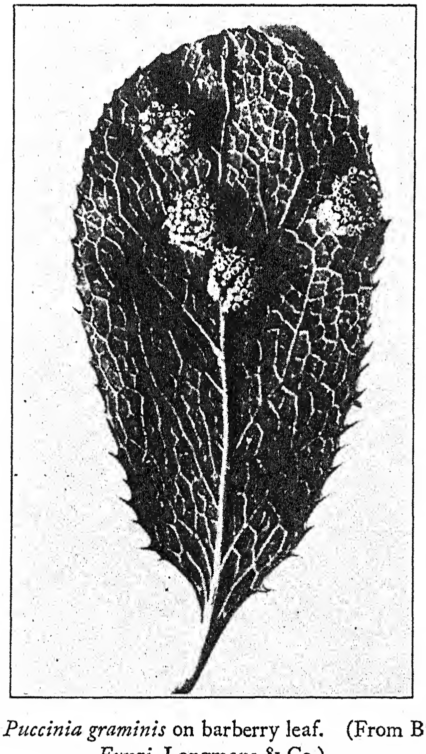


Fig. 163. Aecia of *Puccinia graminis* on barberry leaf. (From Buller's *Researches on Fungi*, Longmans & Co.)

within that leaf. In a few days the barberry leaf becomes thickened in the spot where the mycelium of the rust fungus is growing. On the under surface of this spot cup-shaped depressions develop

which are filled with yellowish binucleate spores. The cup-shaped depressions are called *aecia* (singular, *aecium*) and the spores they contain are *aeciospores*. On the upper surface of the spot minute black specks show the location of flask-shaped structures lined

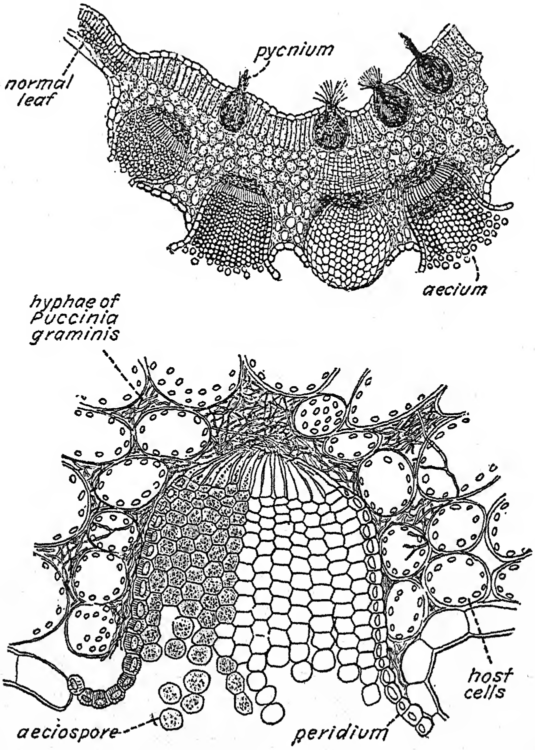


FIG. 164. *Puccinia graminis*. Above, cross section through infected area of barberry leaf; below, diagram of a section through a single aecium. (Upper figure from Sachs, *Textbook of Botany*, Clarendon Press, Oxford; lower after Ward from Duggar, *Fungous Diseases of Plants*, Ginn & Co.)

with hair-like hyphae which form small spores at their tips. These flask-shaped structures are *pycnia* (singular, *pycnium*) and the spores are *pycniospores*.[5] The aeciospores if carried to a wheat

[5] Recent experiments by Craigie indicate that there are two different kinds of basidiospores which may be called (+) and (−). The mycelium from a (+) basidiospore forms (+) pycniospores but no aecia. The mycelium from a (−) basidiospore forms (−) pycniospores but no aecia. The aecia are produced by the union of (+) and (−) mycelia from the basidiospores or by the union of (+) and (−) pycniospores.

plant will germinate and produce a mycelium which will form urediniospores. The mycelium from the aeciospore will not grow in the tissues of the barberry plant. We may summarize these spore forms of *Puccinia graminis* and some facts regarding them as follows:

Spore	*Length of Life*	*Produced on*	*Time*	*Infects*
Urediniospore	Short	Wheat plant	When wheat plant is young	Wheat plant
Teliospore	Long	Wheat plant	When wheat plant is maturing	Nothing (forms basidium)
Basidiospore	Short	Basidium	Spring	Barberry plant
Pycniospore	Short	Barberry	Spring	Nothing
Aeciospore	Short	Barberry	Spring	Wheat plant

By studying the above table it is evident that there are two ways in which *Puccinia graminis* might continue to exist. If there were a continuous fresh supply of young wheat plants urediniospores might produce in young plants mycelia which would form urediniospores which would in other wheat plants produce mycelia forming urediniospores, and so on. Or, putting it briefly, urediniospore — mycelium — urediniospore — mycelium — urediniospore, indefinitely. This might be called a short life cycle. If, however, the time between crops of wheat plants were some months, all the urediniospores, together with the mycelia in the wheat plants, would die, leaving only the teliospores alive, and under such circumstances the barberry would be necessary for the continuance of the existence of the wheat rust fungus. This would involve the long life history with the two hosts and five spore forms.

Since the teliospore is the only form of the wheat rust fungus which lives over the winter in cool climates, and since the basidiospores it produces can infect only the barberry,[6] and since the

From these unions, which may be considered gametic, binucleate aeciospores result. The binucleate condition persists through the urediniospore stage to the teliospore stage when fusion of nuclei occurs. Formerly the pycniospores were considered functionless but the experiments referred to show that they play a definite part in the life cycle of this complex and highly interesting plant.

[6] Aecia of *Puccinia graminis* may be produced on a few other kinds of plants, but these are not common.

fungus cannot live saprophytically, it would appear that the destruction of the barberry would result in the destruction of the wheat rust fungus. There are sections (Australia), however, where no barberry grows, and others (Missouri and more southern states) where few or no aecia develop upon it, and yet stem rust of wheat is found in these localities. In the warmer climates this is easy

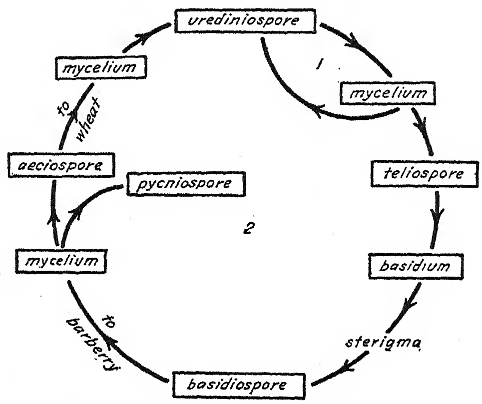


FIG. 165. Diagram of the life-cycle of *Puccinia graminis.*

to explain. In such conditions a fresh supply of young wheat plants (or related plants which are subject to rust) is continually developing through the year, and the rust fungus exists in the short life cycle. In the colder regions, such as Missouri, where the barberry rusts very little and wheat does not grow the year round, either we are mistaken about the over-wintering of urediniospores, or the urediniospores are blown in the early spring from the south where the rust fungus exists in the short cycle. We might picture a wave of red rust advancing northwards from Mexico in the spring. Even though this last picture is the correct one, the destruction of barberry plants in localities where they rust badly may delay the appearance of the rust on wheat long enough to permit the development of normal grain and a full crop.

The mycelium of *Puccinia graminis* is septate,[7] it produces no asci, but forms a basidium and basidiospores. There are many other fungi which form structures similar to the basidium and basidiospore of the wheat rust fungus and they are all called *Basidiomycetes* or basidium fungi. The better known of the

[7] Septate means divided by cross walls.

Basidiomycetes are the rusts, smuts, toadstools, mushrooms, shelf fungi, earth stars and puff balls.

144. **The Smuts.**—The smuts appear as black powdery or waxy masses in blisters on leaves or stems or replacing parts of the flower or fruit. They are destructive parasites of many cultivated crops such as corn, oats, wheat and onions. There are more than 2,000 kinds of smut fungi. Oats, wheat and barley show two important

FIG. 166. Smutted oat heads. Left, loose smut; right, healthy plant.

general types of smut: the covered smuts and loose smuts. In the loose smuts the grain is replaced by a powdery mass of black spores which are exposed and blown away. In the covered smuts the mass of spores is partly covered by the outer parts of the grain

and either blows away less rapidly or forms a somewhat waxy mass. Each of these six smuts is caused by a different kind of fungus which is specific for the disease. The fungus which causes loose smut of wheat will not produce the covered smut of wheat nor will it produce a smut on either oats or barley. These six fungi have

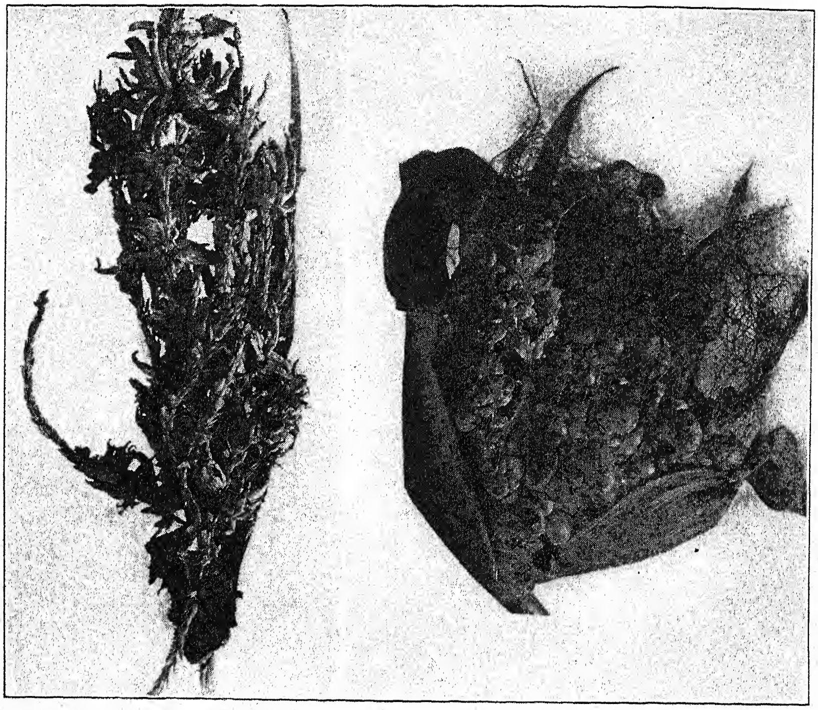


FIG. 167. Corn smut. Left, smutted tassel; right, smutted ear.

only two types of life history. That of the fungi which cause the loose smut of oats and the covered smut of all three grains is briefly as follows:

The spores formed in the smutted heads are blown to the flowers of the wheat, oats, or barley plants and germinate there. The mycelium formed penetrates the glumes and the superficial tissues of the grain. In addition spores on the surface of the grain are planted with the grain. As the grain germinates these spores also germinate and the resulting hyphae penetrate the young plant. As the plant grows the mycelium derived from the spores which

germinated and penetrated the surface of the grain at flowering time and that derived from the spores planted with the grain grow also. Their effect upon the plant is very slight, however, until the time of flowering and the production of grain. Then in

FIG. 168. Sporophores of a shelf fungus, *Fomes fomentarius*, on birch.

those plants in which the smut mycelium is growing the grain is replaced by a mass of black spores. Some of these spores are blown to the flowers of other plants in the same or adjacent fields and others stick to the outside of the healthy grains. Since the mycelium of the smut fungus is in the superficial tissues of the grain or the spores are carried on the surface of the grain, treatment of the grain, before planting, with poisonous substances, such as copper carbonate dust or formalin, in such strength that the spores and mycelium are killed but the grain is unaffected, will protect the new crop.

The fungi causing the loose smut of wheat and barley have a somewhat different life history which necessitates a distinctly different method of control. The spores are blown to the flowers of wheat or barley plants and germinate there. The mycelium formed penetrates the young developing grain and when it has ripened the mycelium exists inside the embryo in the grain, though

no outside evidence of its presence is visible. When such a grain is planted and grows, the mycelium grows within the tissues of the host and at the time of flowering the wheat head or barley head is

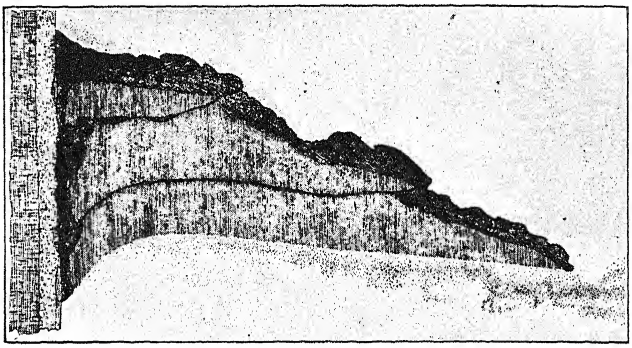


FIG. 169. Section through a shelf fungus showing growth layers and escaping spores. (From Buller's *Researches on Fungi*, Longmans & Co.)

a mass of spores. No treatment affecting the outside of the grain will control these smuts. It happens, however, that the protoplasm of the smut mycelium is more susceptible to heat than that of the grain. It is possible, therefore, by suitable heating of the grain to kill the mycelium within it but to leave the grain alive. Corn smut shows still a third type of life history. The spores are not carried on the seed nor is the mycelium found within the grain. The spores live in soil rich in organic material or in manure, and the basidiospores blown to the young corn plant produce the mycelium, which forms the spores found in the boils on smutted corn plants.

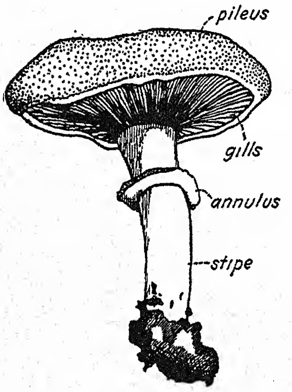


FIG. 170. Sporophore of a mushroom, *Agaricus campestris.*

145. Other Basidiomycetes. — The toadstools, mushrooms, puff balls, shelf fungi and earth stars are saprophytic. The part of the fungus which we commonly see and from which each derives its common name is the spore-bearing part (*sporophore*), the vegetative body existing as filaments in the soil or wood upon which the sporophore eventually appears.

The life history of the common edible mushroom, *Agaricus campestris*, is typical of this group. The mature sporophore is umbrella-shaped, the cap (*pileus*) resting on the upper end of the stalk (*stipe*). This fleshy sporophore is composed of fungous hyphae which remain associated in a mass instead of growing as separate threads. From the under surface of the pileus hang thin

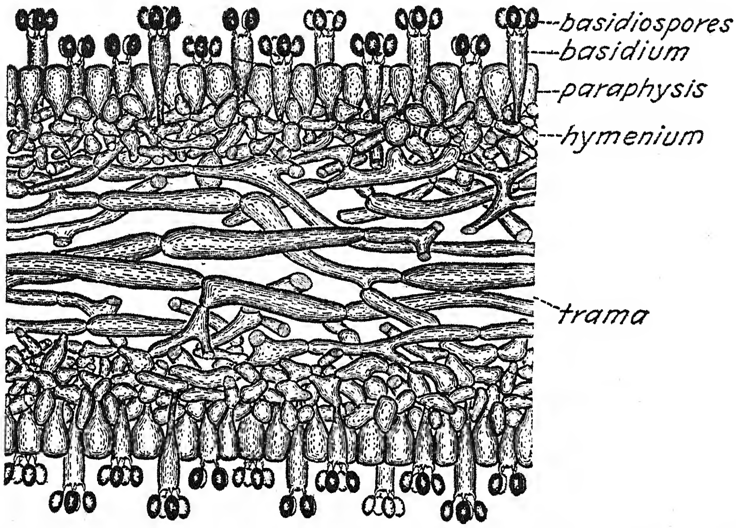


Fig. 171. A section through the gill of a mushroom, *Coprinus comatus*. Section cut perpendicular to the surface of the gill. From Buller's *Researches on Fungi*, Longmans & Co.)

plates of tissue radiating from the stipe somewhat like the spokes of a wheel. These are *gills* (*lamellae*). Each gill consists of an interior portion of long slender hyphae from which extend short thick hyphae which cover the entire surface of the gill and compose the *hymenium*. The hyphae of the hymenium are of two types. Some bear at their outer ends four short stalks (sterigmata) on each of which a basidiospore develops. These hyphae are called basidia, though different in appearance from the basidia of the rust fungi. The other hyphae are sterile (bear no spores) and are called *paraphyses* (singular, *paraphysis*). A single pileus may form as many as two billion basidiospores. The basidiospores fall from the gills, and being microscopic in size may be widely scattered by the wind. On germination they form mycelia which consist of

masses of separate filaments and live in the soil, digesting and using for food the organic matter found there. The more organic matter there is present, the better the mycelium grows. The sporophores originate from this underground mycelium, appearing first as small rounded masses of interwoven hyphae known as "buttons." Within the button gills and a stipe are differentiated. The stipe elongates, the pileus expands and in a few hours a button may become a mature sporophore. In the young sporophore a thin layer of hyphae extends from the margin of the cap to the stipe, covering the gills. As the stipe expands this layer is torn at the edge of the pileus and may remain as a ring around the stipe. In some of the mushrooms and toadstools, though not in *Agaricus campestris*, the young sporophore is covered also with a membrane which may be found in bits on top of the mature sporophore and as a *cup* or *volva* at the base of the stipe. Separated bits of the mycelium of the mushroom will also grow and it may thus be reproduced without basidiospores.

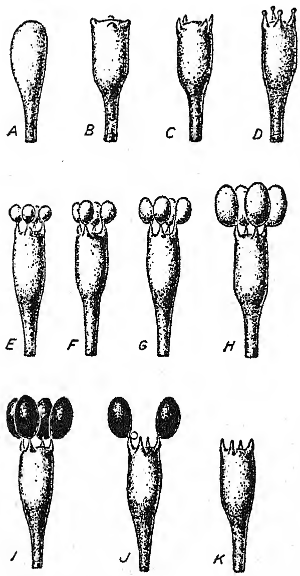


FIG. 172. The development of a basidium and the basidiospores of a mushroom. (From Buller's *Researches on Fungi*, Longmans & Co.)

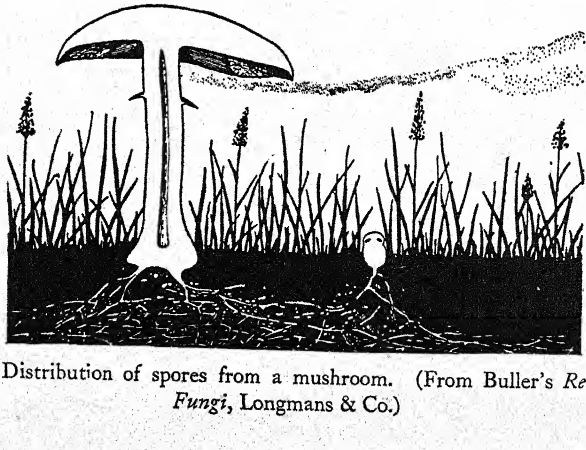


FIG. 173. Distribution of spores from a mushroom. (From Buller's *Researches on Fungi*, Longmans & Co.)

The spores of the puff balls and earth stars are formed inside the sporophore and puff out in a cloud when the sporophore is squeezed. Many of the shelf fungi have pores instead of gills

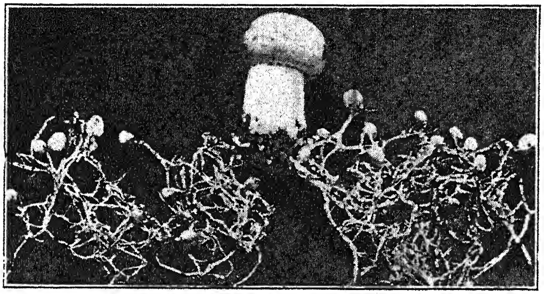


Fig. 174. Mycelium in thick strands (rhizomorphs) and "buttons" of the mushroom, *Agaricus campestris*. (From Atkinson, *Mushrooms, Edible and Poisonous*, Henry Holt & Co.)

on the under surface, the walls of the pores being lined with basidia. These fungi are responsible for much wood decay; railroad ties, trees, lumber are excellent food for them and their sporophores

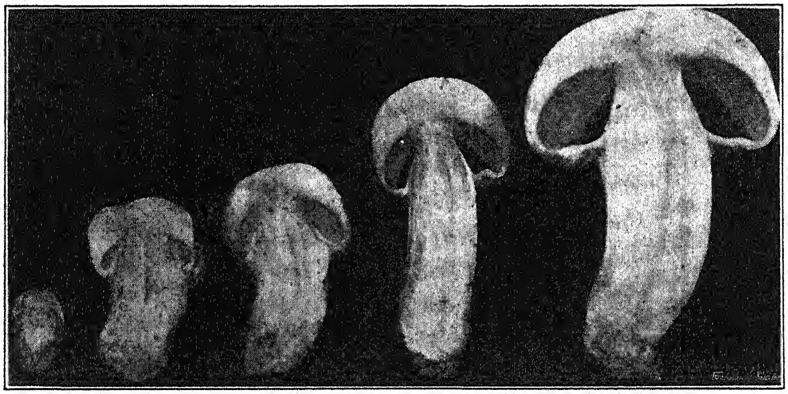


Fig. 175. The development of the sporophore of the mushroom, *Agaricus campestris*, from the "button." (From Atkinson, *Mushrooms, Edible and Poisonous*, Henry Holt & Co.)

may frequently be found in such locations. We should remember, however, that before the sporophore appears the mycelium has been growing within the substratum and that most of the decay

has already occurred. Removing the sporophore will be of little help in stopping decay. Impregnation of the wood with poisonous material (such as creosote), or prevention of the entrance of the fungus, is the only effective means of protection.

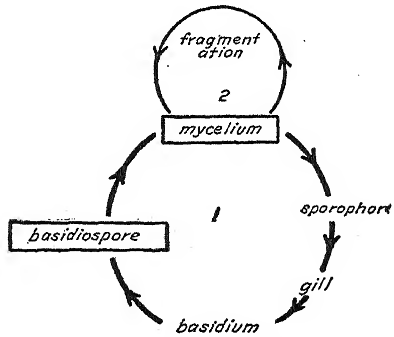


FIG. 176. Diagram of the life-cycle of a mushroom.

146. Summary.—In addition to the kinds of fungi of which we have described examples there are others. Some consist of naked masses of protoplasm which flow over the surface of wood or leaves,

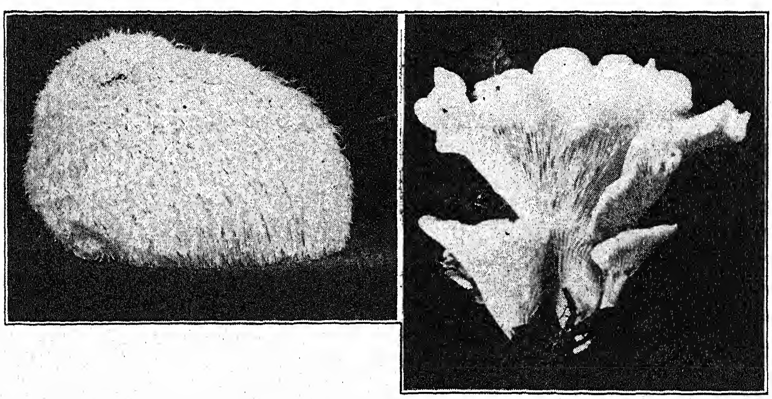


FIG. 177. Two fleshy fungi. Left, *Hydnum crinaceum;* right, *Pleurotus petaloides.*

digesting them, and eventually forming spores. These are called slime molds or *Myxomycetes.* Some of these produce diseases in plants. There are other fungi which do not fit, at least what we know of them does not fit, any of the groups mentioned, and they

are placed in a group by themselves and called the *Fungi Imperfecti*, because no gametic reproduction has been found in them.

The fungi are very diverse in morphology and in physiology. They range from the single-celled bacterium to the many-celled fleshy sporophore of the mushroom, they may be saprophytes, facultative parasites,[8] or obligate parasites. They reproduce by fission, by budding, by spores of almost infinite variety, by various

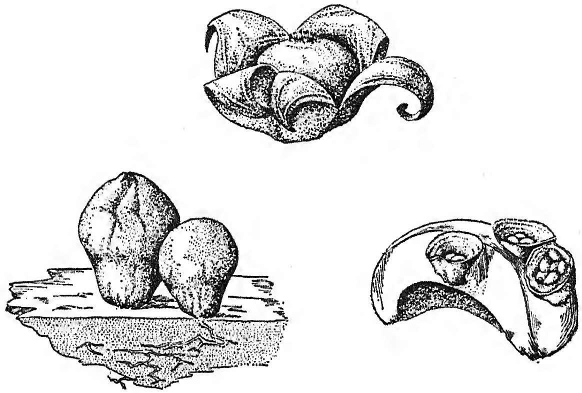


FIG. 178. Above, an earthstar (*Geaster*); below, left, puffballs (*Lycoperdon*) growing on a piece of bark (notice the rhizomorphs in the bark); right, bird's nest fungi (*Crucibulum*) growing on a piece of hickory nut shell.

types of gametic reproduction, and by fragmentation. And yet their diversity is largely superficial. Each is composed of the fundamental structural units, cells; each carries on the fundamental life processes of absorption, digestion, respiration; no matter how they reproduce, it is fundamentally the isolation of a bit of protoplasm capable of continued growth and development. Life is infinite in its variety and yet fundamentally always the same.

[8] A facultative parasite can exist either parasitically or saprophytically.

CHAPTER XVIII

The Algae

Astounding in their variety as the fungi may be to the uninitiate, they comprise but a part of the kinds of plants which are called Thallophytes. Many thallus plants, as was pointed out earlier, contain chlorophyll and are called *algae* (singular, *alga*). This pigment, as in other green plants, is important in their nutrition, and its presence gives them a source of food entirely different from that of the fungi. Morphologically, except for the plastids which the algae have but the fungi do not, and in their methods of reproduction the two groups are much alike.

Undifferentiated or Slightly Differentiated Algae

147. Protococcus.—Some of the algae, like the bacteria and yeasts, are single-celled. One kind forms a green coating on tree trunks, fence posts, and similar objects. This green coating is usually more evident on the north side of a tree trunk and after rains. It is composed of innumerable spherical green cells, which may be separate from one another or grouped in colonies. This alga we call *Protococcus*. The *Protococcus* plant consists of a single spherical cell about as large as the average yeast plant. There is a thin but distinct cell wall enclosing a bit of protoplasm. A single large horseshoe-shaped chloroplast occupies most of the interior of the cell. Between the arms of the horseshoe, in the cytoplasm, is a single nucleus. This minute cell is an individual living plant

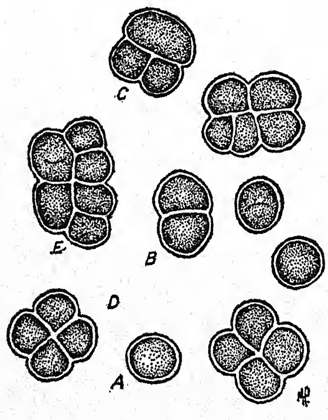


Fig. 179. *Protococcus.* Single individual plants and colonies. Stages in the formation of a colony are shown in *A*, *B*, *C*, *D* and *E*. (From Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

capable of carrying on photosynthesis, absorption, digestion, growth

and reproduction. Reproduction is accomplished by cell division, the mother cell dividing into two daughter cells, which may grow in size until each eventually reaches the size of the mother plant.

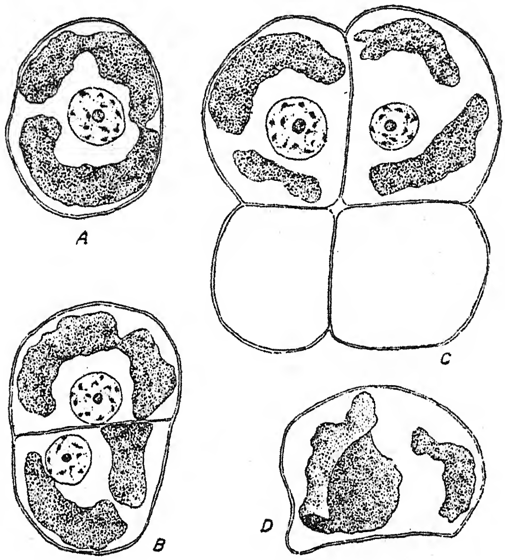


FIG. 180. *Protococcus.* Sections of plants showing nucleus and chloroplast. (From Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

The entire mother plant becomes the two daughter plants, no part of the parent dying. While in reproduction the individual disappears, the protoplasm does not, being transferred without loss to the two daughter cells. The protoplasm of the *Protococcus* plant need never die of old age. It is potentially immortal. The two daughter plants resulting from reproduction may not separate at once but may remain stuck together and may divide again before separation. Thus a colony of two or more individuals may result. *Protococcus* constructs its necessary foods from carbon dioxide and water by photosynthesis; mineral salts and

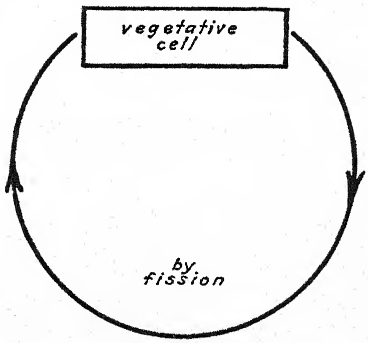


FIG. 181. Diagram of the life-cycle of *Protococcus.*

nitrogen and water are absorbed from the substrate on which it lives; gaseous oxygen is secured from the air. *Protococcus* is quite resistant to desiccation, which fact enables it to live on a tree trunk which is alternately wet and dry. In our hemisphere *Protococcus* develops more luxuriantly on the north side of tree trunks than on the south side. This is because sunlight, particularly the ultraviolet light, is injurious to protoplasm exposed directly to its rays as the protoplasm of the thin and transparent-walled *Protococcus* cell is exposed.

Protococcus in its reproduction recalls the bacteria, though the presence of a chloroplast results in a physiology quite different from that of the fungi.

There are other kinds of algae related to *Protococcus* which exist as one-celled individuals more or less permanently associated together in colonies. The shapes and arrangement of the cells

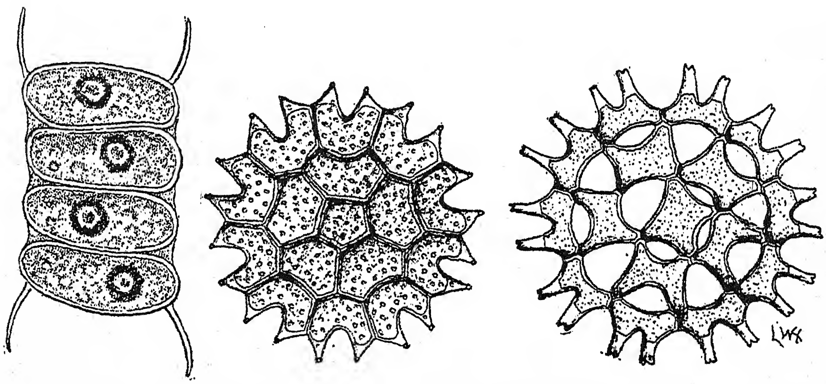


FIG. 182. Simply constructed algae. Left, *Scenedesmus* (from Oltmanns, *Morphologie und Biologie der Algen*, Gustav Fischer, Jena). Middle and right, two species of *Pediastrum* (from Conn, *Connecticut Algae*, Connecticut State Geological and Natural History Survey).

vary greatly in different kinds. Some of them are illustrated in Figure 182. Their life cycles are as simple as that of *Protococcus*, and their methods of reproduction similar.

148. Desmids.—Another group of unicellular algae is the desmids. A desmid usually consists of a cell made of two similar halves but containing one nucleus; in each half there is a single bright green chloroplast. There is usually a constriction between the two halves. The twin character and the beauty of the chloro-

plasts make the desmids an interesting group of microscopic plants. They reproduce by cell division, each plant dividing into two halves and each half developing the missing half and forming

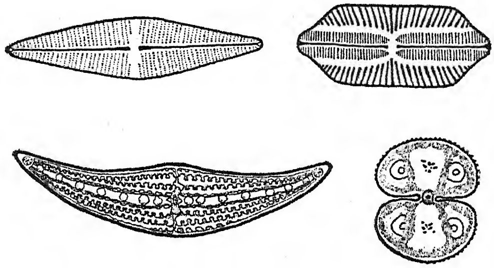


FIG. 183. Above, two species of diatoms; the contents are not illustrated. Below, two species of desmids, showing chloroplasts, pyrenoids, vacuoles, and nuclei.

a complete individual. Gametic reproduction also occurs, the protoplasts of two desmids fusing to form a zygote, from which eventually arise two new desmids.

Protococcus by reproduction forms temporary colonies. In many kinds of algae the colonies formed are permanent, the cells never separating except through injury or other accidental means.

149. Spirogyra.—One such alga consists of cylindrical cells attached end to end and forming threads which may be a foot or more in length. Each cell possesses a thin wall, which is lined with a layer of cytoplasm; embedded in the latter are one or more spirally coiled ribbon-like chloroplasts. Because of these spirally

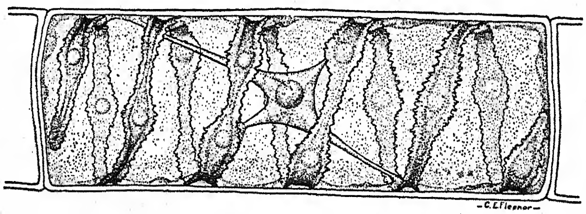


Fig. 184. A vegatative cell of *Spirogyra.*

arranged chloroplasts this alga is called *Spirogyra.* There are many species of *Spirogyra,* differing from one another in size, number of chloroplasts per cell and in the details of reproduction. In all of them a nucleus is located in the center of the cell in a large central vacuole. It is surrounded by a layer of cytoplasm,

from which cytoplasmic threads extend across the central vacuole to the peripheral layer of cytoplasm which lines the cell wall. On the outside of the cell wall there is a mucilaginous coating which makes *Spirogyra* slimy to the touch. These filaments usually float in the water in masses buoyed up by gas bubbles (see Fig. 381).

Each cell of a filament is like every other cell, except the terminal cell, whose end wall may be rounded because the internal pressure is not balanced by that of an adjoining cell. Though not normally found alone a single cell is capable of independent existence. We

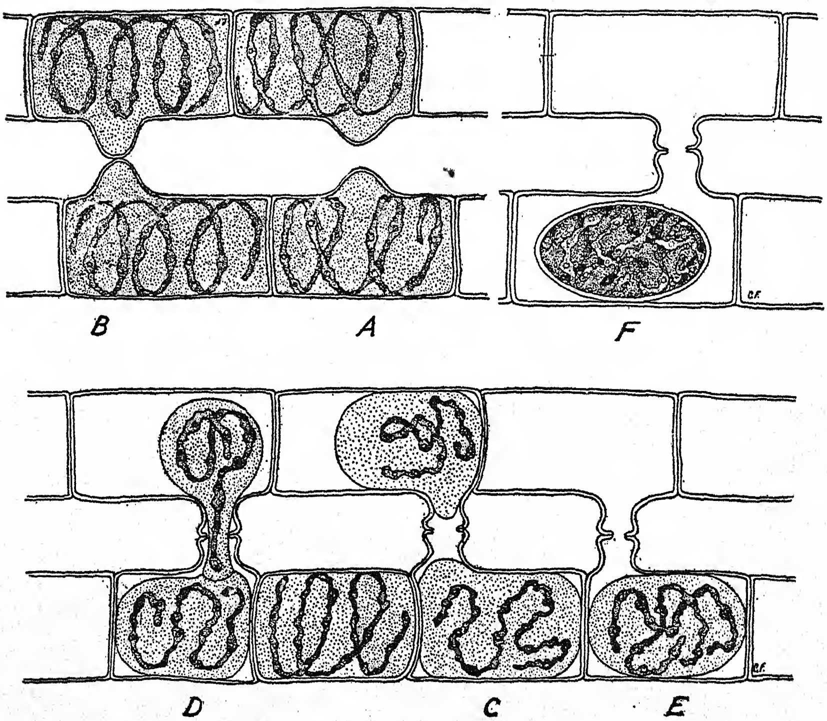


FIG. 185. Stages in the gametic reproduction of *Spirogyra*. *A* and *B*, the beginning of the formation of the conjugation tube; *C*, *D* and *E*, stages in the union of the gametes; *F*, a mature zygote, still surrounded by the wall of the non-motile gamete. The nuclei are not illustrated.

may therefore consider each cell as a plant and the filament a colony. Or, because we almost always find several cells attached to each other, we might consider the filament a plant made up of

several identical cells. The former conception is the more convenient for us.

When a *Spirogyra* cell divides, the new cell wall always develops perpendicular to the long axis of the cell. The result is a narrow thread of cells instead of a plate-like or spherical mass.

Besides reproducing by cell division [1] *Spirogyra* also reproduces gametically. After a number of generations formed by cell divisions the filaments become paired. A portion of the wall of each cell becomes softened and is pushed out by internal pressure into a short protrusion. The protrusions from the plants in one filament meet those of another filament, frequently mushrooming somewhat where the tips touch. The walls at the tips of the protrusions dissolve away, leaving open tubes connecting the pairs of cells, and making the two filaments look much like a ladder. Through these tubes (the *conjugation tubes*) the protoplasts of the plants of

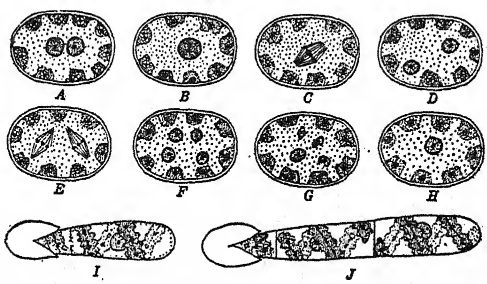


FIG. 186. Diagrams to show nuclear behavior in the formation and germination of the zygote of *Spirogyra*. The two nuclei, one from each gamete (*A*), fuse (*B*) and the resulting nucleus divides to form four (*C, D, E, F*); three then disintegrate (*G, H*). The zygote germinates (*I, J*). *I* and *J* are drawn to a smaller scale than the others and show a surface view. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

one filament move into the cell cavities of the other filament. The two protoplasts within each cell cavity unite, the two masses of cytoplasm becoming indistinguishable from one another, the two nuclei uniting to form one, and the chloroplasts largely losing their characteristic form. The two protoplasts which unite are gametes, and the product is a zygote. This bit of protoplasm,

[1] If the single cell is considered an individual, then cell division is reproduction; if the filament is considered an individual plant, cell division would be a part of the growth of the individual.

consisting of the protoplasts of two cells, secretes a roughish wall of three layers, a thick outer one, an impermeable middle one and a thin elastic inner layer. The zygote contains considerable food, at first starch, which is later changed to oil. In this form *Spirogyra* may remain alive under conditions of temperature or drought which kill the vegetative plants.

After a period of dormancy, and in the presence of abundant water and a moderate temperature, the contents of the zygote absorb water, swell and burst the outer layers of the wall, protruding as a slender tube in which the characteristic spiral chloroplasts

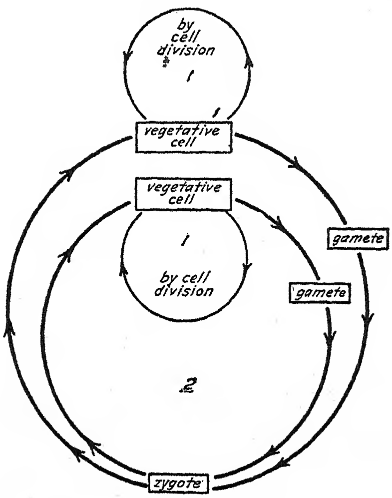


FIG. 187. Diagram of the life-cycle of *Spirogyra*.

are reorganized. The nucleus of the zygote divides during this process to form four nuclei, three of which degenerate; the significance of this will appear later. By further cell division this single plant may become many, arranged in the characteristic filament.

Spirogyra is but one of hundreds of different kinds of algae which exist as filaments of cells. There are also relatives of these filamentous algae which form colonies shaped like flat ribbons or like broad flat leaves. One of these is *Ulva*, the sea lettuce, common along the shores of the oceans. Among the filamentous forms there are great differences in size and shape of cells and of their chloroplasts and in methods of reproduction. No others have the spirally twisted ribbon-shaped chloroplasts of *Spirogyra*, and few

of them in reproduction form conjugation tubes. In some the gametes are differentiated into two kinds, a large non-motile one uniting with a small motile one. Some of these kinds of algae form swimming spores called zoöspores. Brief descriptions of a few of the commoner kinds will illustrate some of these differences.

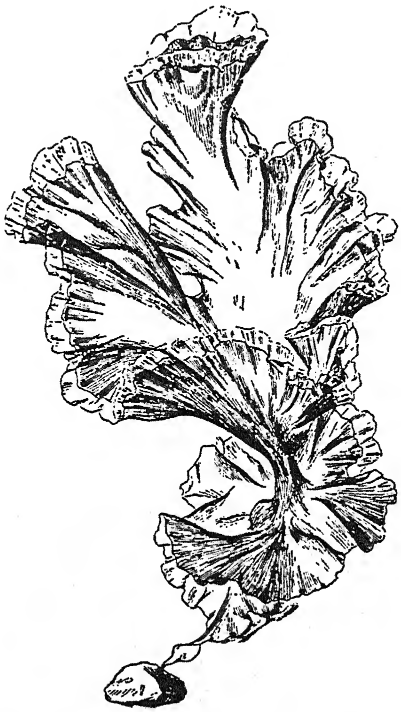


FIG. 188. *Ulva Lactuca.* ×1/2. (After Thuret from Oltmanns, *Morphologie und Biologie der Algen*, Gustav Fischer, Jena.)

150. Ulothrix.—In *Ulothrix* the cell at one end of a filament is elongated and colorless, and becomes attached to a rock or other supporting object in the water. It is called the *holdfast*. This is an example of differentiation among the cells of a filament, and we are probably justified in considering such a filament a many-celled plant, although most of its cells are identical and can continue to live if separated. The chloroplasts are flat; and each cell possesses one, which lies against the cell wall in a band. Reproduction occurs by means of zoöspores. These are formed by successive

cell divisions of the protoplast of one cell until many small cells are enclosed by the original cell wall. They escape by means of a small hole in the wall, and swim actively in the surrounding water

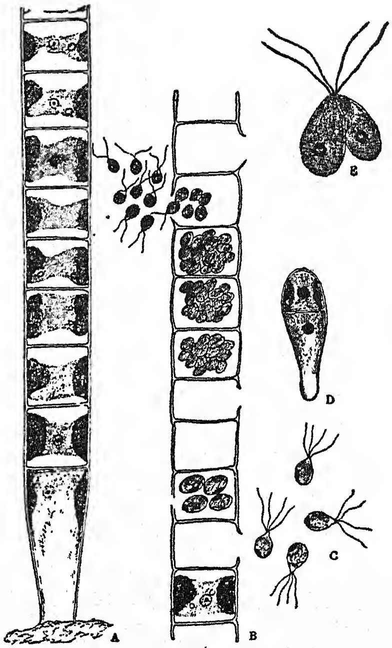


Fig. 189. *Ulothrix zonata.* *A*, portion of a filament showing holdfast cell at base; *B*, portion of a filament which has formed gametes (above) and zoöspores (below); *C*, zoöspores which have escaped; *D*, a germinating zoöspore; *E*, fusing gametes. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

by means of their flagella. After a period of such activity they become motionless, lose their flagella, and develop by elongation and cell division into new filaments, each spore becoming the parent cell of an entire filament. Gametes are formed in much the same way as are the zoöspores, escape and move around in the water in the same way; development, however, occurs only after two gametes have united and formed a zygote; the two gametes which unite are identical in appearance. The zygote, like that of *Spirogyra*, becomes a thick-walled dormant body; it finally itself reproduces by means of zoöspores which become new filaments.

151. **Oedogonium.**—Another common filamentous green alga is *Oedogonium*. The basal cell of the filament is differentiated to form a disc-like holdfast. The chloroplast of each cell forms a web or network against the cell wall. The zoöspores are composed of protoplasts which have become somewhat transformed and have escaped from their cell walls. Two sorts of gametes are formed. One sort is, like the zoöspores, formed by the rounding up of the

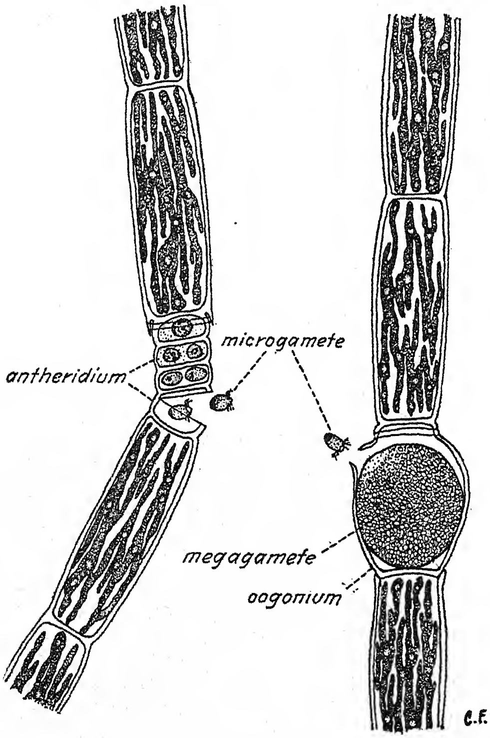


Fig. 190. *Oedogonium*. Portions of two filaments showing the reticulate chloroplast and microgametes and megagamete.

protoplast of a single vegetative cell; but it does not escape from the surrounding cell wall—only a very small hole is developed in this wall. The other sort of gamete is very small; many are formed by division of the protoplasts of rather short cells of the filament, and escape from the walls into the surrounding water, where they swim by means of *cilia* (singular, *cilium*; tiny vibrating hairs of

protoplasm). Some of them enter the small hole in the wall surrounding the large gamete and there the gametes unite, one large one with one small one. The two sorts of gametes may be distinguished by the names *megagamete* and *microgamete*. The rest of the history is much as in *Ulothrix*.

152. Vaucheria.—Still another common filamentous alga is *Vaucheria*. It grows commonly on soil instead of in water. The filament of this plant is coenocytic—it consists of many cells not separated by walls. In this respect *Vaucheria* resembles the

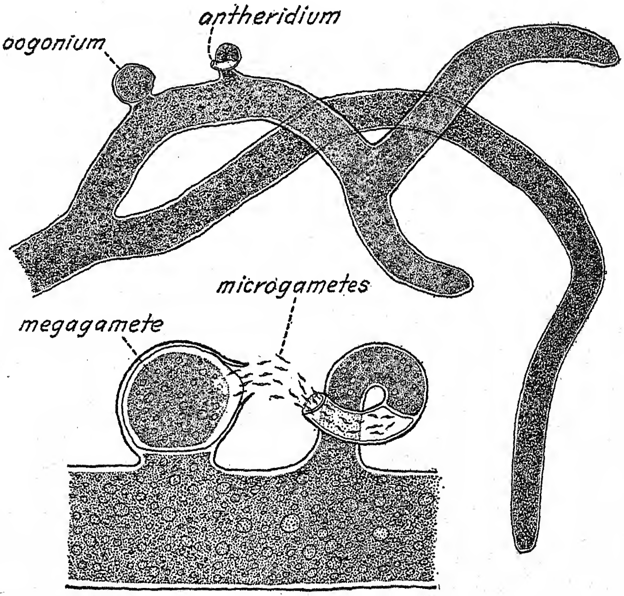


FIG. 191. *Vaucheria.* Above, habit sketch showing body which lacks cross walls; below, fertilization; large megagamete, small motile microgametes.

Phycomycetes, and, as has already been mentioned, this group of fungi owes its name to the fact that it resembles in this and other respects certain algae. Within the wall of a filament are cytoplasm, many nuclei, and many small chloroplasts; in the central part of the filament there is a large central vacuole. The zoöspores are about as large as those of *Oedogonium*, but they consist, like the filament, of many cells; they are formed in compartments cut off by walls at the tips of filaments. The gametic reproduction also resembles that of *Oedogonium* in some ways; the gametes are of

two sorts, and a large one must unite with a small one before reproduction can be completed; and the small kind of gamete is motile and gains access to the larger non-motile gamete through a hole in the wall surrounding the latter. These gametes are produced in special compartments which arise as side branches of the filament and are separated from the rest of the filament by cross walls. Because of the intimate association of the cells and the differentiation between them into vegetative cells, spores, or gametes, *Vaucheria* must be considered a many-celled plant rather than a colony of single-celled individuals.

153. **Chlamydomonas.**—Among the one-celled green algae there is one group composed of individuals which resemble Protococcus in their tiny size and simple structure, but which differ in possessing flagella during most of their life cycles. They resemble superficially the zoöspores of such an alga as *Ulothrix*. A common member of this group is *Chlamydomonas*. It is composed of a single oval cell almost filled by one large chloroplast. Two flagella of cytoplasm project through the cellulose wall at one end; and near this end also is a small spot of reddish pigment which is sensitive to light and which causes the small plant to swim towards the source of light. Other members of this group are found commonly in colonies, flat or spherical. The large spherical colonies of *Volvox* are composed of hundreds of flagellated cells. Reproduction of such algae is by means of zoöspores and gametes.

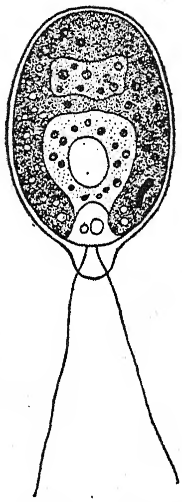


FIG. 192. *Chlamydomonas*, showing cup-shaped chloroplast, nucleus, pigment spot, and flagella. ×900. (From Collins, *Green Algae of North America*, Tufts University Studies.)

154. **Flagellates.**—Somewhat related to the above group are one-celled motile organisms called flagellates. A common flagellate is *Euglena*. These plants have no definite cell walls, and frequently engulf solid particles of food which they then digest; some of them lack chlorophyll. For these reasons they appear to be as closely related to one-celled animals as to other one-celled plants, and are sometimes classed as animals, sometimes considered to represent the ancestral forms from which both plants and animals may have been derived. All of the algae so far described, with their close relatives, with the

possible exception of the flagellates, are classed in one group, the *Chlorophyceae* (green algae).

155. **Diatoms.**—Another rather peculiar group of algae, which is not always classed with the green algae, is the diatoms (Fig. 183). These plants are of various shapes, usually bilaterally symmetrical. Their most striking character is the fact that their cell walls are delicately and minutely sculptured and impregnated with silica. The wall consists of two halves (valves) one of which fits within the other. The protoplast within the walls contains a single nucleus and usually two chloroplasts. There is also a yellowish or brownish pigment which partially conceals the green color of the plastids. The diatoms reproduce by cell division, each of the two new protoplasts retaining one of the valves and forming a new one. As a result one of the new diatoms is smaller than the other. Sometimes the protoplasts of two small diatoms escape from the valves and unite. From the zygote so formed a full-sized diatom arises.

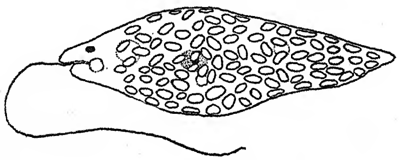


Fig. 193. A common flagellate, *Euglena;* a single flagellum, a nucleus, several chloroplasts, and a pigment spot are visible.

The diatoms live in fresh or salt water, sometimes in colonies, and may be found floating free in the water or attached to other plants. When they die the organic matter of the wall decays, but the form of the valves and the sculpturing of the walls of many kinds remain intact because of the silica which impregnates it. These walls sink to the bottom and accumulate in huge quantities. In California there are deposits of diatomaceous earth miles long and wide and hundreds of feet thick. In a cubic centimeter of this material there may be over 2,500,000 diatom shells. There are over two thousand kinds of diatoms, distinguishable by their shape and the sculpturing of their walls. Because diatomaceous earth is composed of minute, uniform, sharp-edged bits of hard material, it is frequently used as a fine abrasive, for instance in tooth paste and polishing powders.

156. **Blue-Green Algae.**—A number of small algae are classed together because of a blue pigment which they possess in addition to chlorophyll. They are called the *blue-green algae* or *Myxophyceae.*[2]

[2] Also called *Cyanophyceae.*

They are single-celled plants usually associated in filamentous or spherical colonies, which colonies in turn are frequently grouped in large irregular masses held together by a jelly-like material.

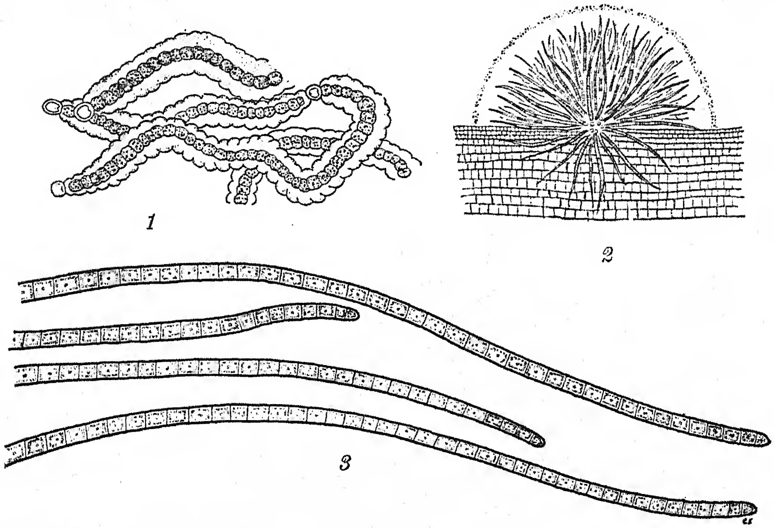


FIG. 194. Blue-green algae. *1*, *Nostoc commune*; *2*, *Rivularia borealis* attached to a bit of a stem; *3*, *Oscillatoria*. (*1* and *2* from Tilden, *Minnesota Algae*, University of Minnesota Press.)

The structure of each cell is extremely simple. There is no visibly differentiated nucleus and no chloroplast. The entire cell is simply a bluish green, apparently undifferentiated protoplast, surrounded by a cell wall. Reproduction is by cell division. The color of large masses of these plants may be almost black; some kinds possess a red pigment, and one of these is said to have given the Red Sea its name. One common blue-green alga is *Oscillatoria*, which owes its name to a slow oscillation of its filaments.

Differentiated Algae

Some of the algae, particularly those which grow in the seas, consist of great masses of cells, not all alike as in *Spirogyra*, but quite different from each other in structure and activities.

157. **Fucus.**—An example of such plants is the rockweed, *Fucus vesiculosus*. It grows attached to rocks, piles or similar objects between the lines of high tide and low tide, and is alternately covered

with sea water and exposed to the air as the tide flows in and out. A single mature plant is from six inches to a foot long. It consists of a slender stalk or stipe, which is somewhat enlarged at the base [3] where it was fastened to the rock or wooden pile, and forked at the upper end into flat, ribbon-like branches which may fork

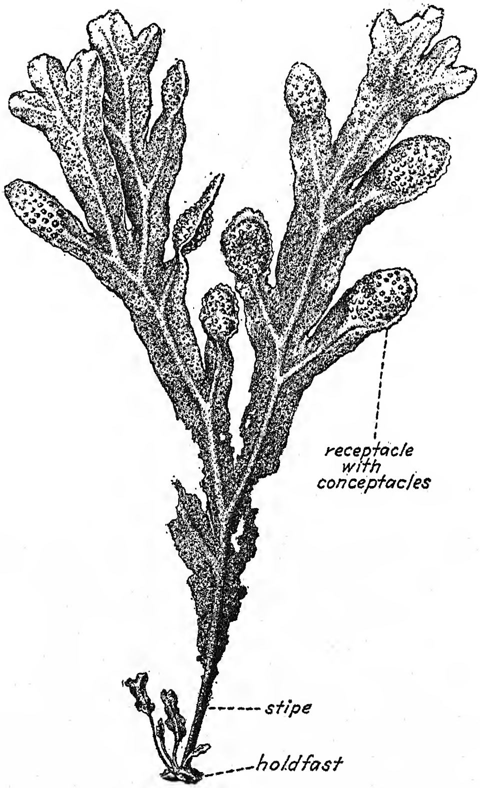


FIG. 195. *Fucus*. Mature plant, ×1/3. No bladders are shown. (From Oltmanns, *Morphologie und Biologie der Algen*, Gustav Fischer, Jena.)

again and again into other branches. The branches have a rib which extends longitudinally through them, and in pairs on either side of this midrib are swellings filled with gas. These are called bladders, and they help float the *Fucus* plant when it is immersed in the sea. The mature *Fucus* plant consists of hundreds of thousands of cells. Those near the surface are small, regularly

[3] This part of the plant is called the *holdfast*.

arranged and with their longer diameter perpendicular to the surface. They make up an *epidermal layer*. Under the epidermis are several rows of larger cells somewhat less compactly arranged.

FIG. 195*a*. *Fucus*, growing on rocks exposed by low tide. Other algae, brown and red, are visible.

They are called the *cortex*. Within the cortex is a central portion called the *medulla* composed of long cells arranged end to end in branching interlacing filaments. The outer layer of the wall of the medulla cells is gelatinous and this jelly fills up the interstices between the cells. Chloroplasts are present in the cells, particularly in those of the cortex, though there is also a brown pigment which conceals the green and gives the plant a dark olive-brown color.

Reproduction is gametic. Some of the tips of the branches are swollen, and just under the surface are dots each less than the size of a pin head. These dots are spherical cavities which are connected with the outside by pores. Each swollen tip is called a *receptacle* and each spherical cavity a *conceptacle*. Within the conceptacles the gametes are formed. Two sorts of gametes are produced. One is spherical, dark olive-green in color, with no organs of locomotion and large enough to be visible to the unaided eye. It is called the megagamete (big gamete).[4] The other is somewhat pear-shaped with a spot of yellow pigment in it, has two laterally placed flagella, of unequal length, which enable it to swim, and is smaller than the average yeast cell. It is called the

[4] The megagamete is also called an *oösphere*, *unfertilized egg*, or *female gamete*.

microgamete (little gamete).[5] Each gamete is a single cell with a single nucleus. In *Fucus vesiculosus* some plants bear megagametes only and others bear microgametes only, but these plants do not differ in their external appearance.

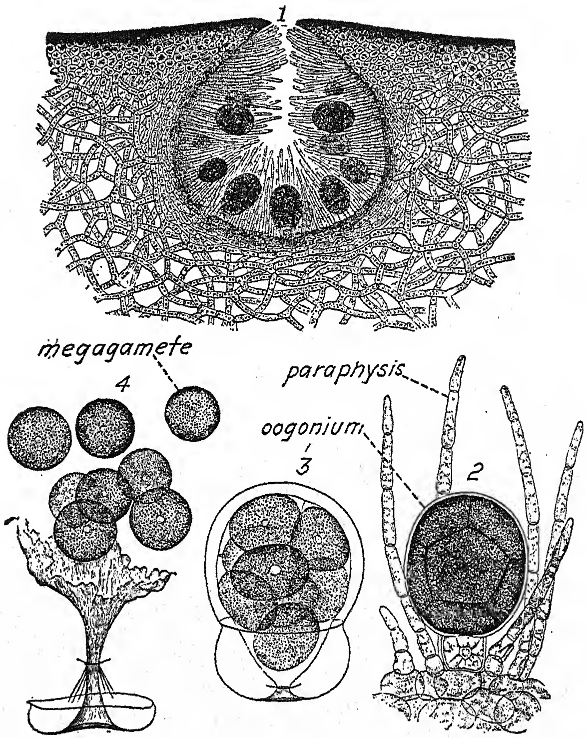


FIG. 196. *Fucus*. *1*, section through oögonial conceptacle, ×30; *2*, an oögonium containing megagametes, ×120; *3*, *4*, oögonial wall breaking and releasing eight megagametes, ×120. (After Thuret from Kerner, *Natural History of Plants*, Henry Holt & Co.)

The megagametes are borne on the inner wall of the conceptacle among some slender hairs which point toward the opening. From among the cells which make up the wall of the conceptacle one grows out and divides transversely. The cell nearest the wall of the conceptacle forms a stalk, the other enlarges and its single nucleus undergoes three successive series of divisions, resulting in the production of eight nuclei. Furrows then develop in the

[5] The microgamete is also called the *sperm*, *antherozoid*, *spermatozoid*, or *male gamete*.

cytoplasm, which results in each nucleus and its surrounding cytoplasm being separated from every other nucleus and its surrounding cytoplasm. Each of the cells thus formed is a megagamete and the structure in which the eight megagametes are borne is called an *oögonium* (plural, *oögonia*). Each conceptacle contains a hundred or more oögonia.

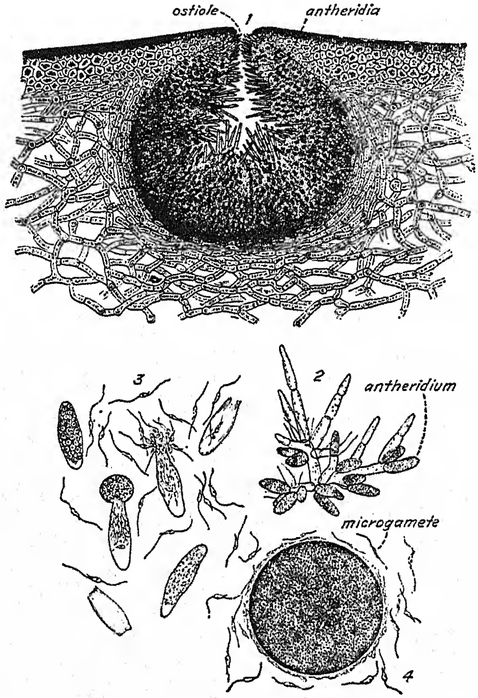


FIG. 197. *Fucus.* *1*, section through antheridial conceptacle, ×30; *2*, hairs with antheridia, ×100; *3*, microgametes escaping from antheridia, ×225; *4*, megagamete surrounded by microgametes, ×225. (After Thuret from Kerner, *Natural History of Plants*, Henry Holt & Co.)

The microgametes develop somewhat similarly in sacs called *antheridia* (singular, *antheridium*). Branching hairs grow out from the walls of the conceptacles. At the tips of these hairs are uninucleate oval cells. The nucleus in each of these cells undergoes six successive series of divisions and so forms sixty-four nuclei. Each nucleus and its surrounding cytoplasm forms a microgamete.

The partial drying of the receptacles which occurs when the

Fucus plants are exposed to the air at low tide causes them to shrink, and the mature antheridia and oögonia break loose and ooze out through the pores. The former appear as orange yellow drops, the latter as dark olive green drops, on the surface of the receptacles. At this time it is possible to distinguish between the plants producing megagametes and those which form the micro-

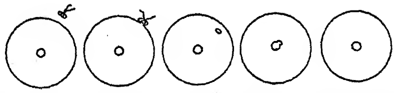


FIG. 198. Diagrams to show fusion of microgamete and megagamete of *Fucus*.

gametes. As the tide returns, the oögonia and antheridia are washed off into the sea water and burst, setting free the megagametes and microgametes. The former, being heavier than sea water and without organs of locomotion, sink toward the bottom. The latter swim away from the light (are negatively phototactic), come into contact with the megagametes, and stick fast to their surfaces. A dozen or more microgametes may be attached to the surface of a

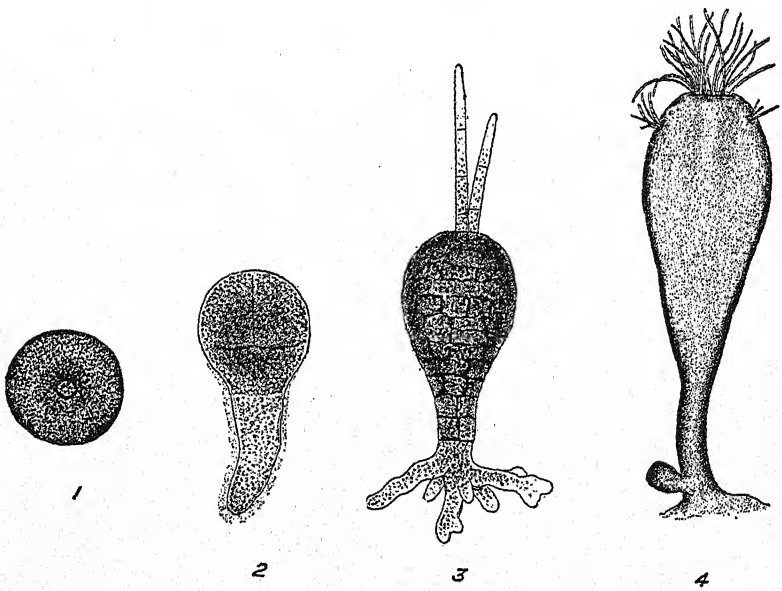


FIG. 199. *Fucus*. Stages in the development of a young *Fucus* plant. *1*, zygote; *2*, *3*, *4*, young plants. *1* and *2* are more highly magnified than *3* and *4*. (Adapted from Oltmanns.)

single megagamete and by the beating of their flagella may make it spin around in the water. In a short time one microgamete enters the megagamete, where its cytoplasm soon becomes indistinguishable from that of the megagamete, while its nucleus moves to the center and unites with that of the megagamete. As soon as one microgamete enters, the megagamete forms about itself a tough wall and the other microgametes fall away. The megagamete is now a zygote.[6] The union of the two gametes is called *fertilization*.[7] The zygote almost at once forms about itself a thin cellulose wall, and produces a tubular outgrowth by which it becomes

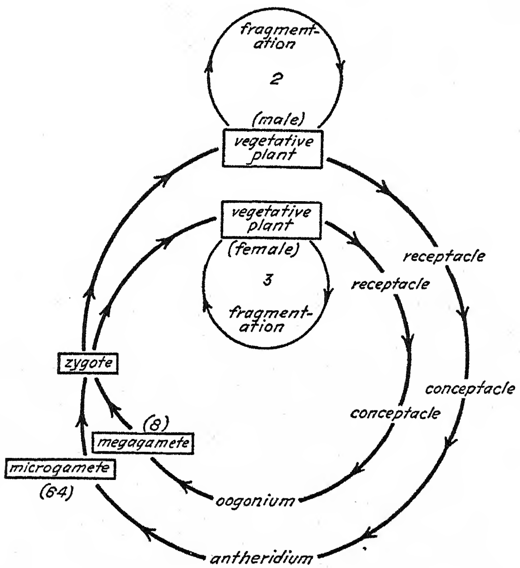


FIG. 200. Diagram of the life-cycle of *Fucus vesiculosus*.

attached to some object. It then divides into two cells and these divide and their daughter cells divide, so that the young plant consists of many cells; the walls are formed in various directions; the whole mass of cells is pear-shaped. One of the cells at the extreme tip is an *apical* cell. It corresponds to the embryonic region in a sunflower root tip or stem tip and all new cells originate from the division of this special cell or of other apical cells formed

[6] It may also be called a *fertilized egg*, an *oöspore*, a *gametospore*, or an *oösperm*.

[7] When the gametes are of approximately the same size their union is usually called *conjugation*. Synonyms for fertilization are *fecundation* and *syngamy*.

from it. As new cells are formed some become epidermal cells, some cortex cells, and some medulla cells. This change in the morphology and physiology of cells is differentiation. Without such differentiation the division of the zygote would result in a mass of cells which would be all alike. In *Protococcus* and *Spirogyra* there is no differentiation; why we do not know, any more than we know the why of differentiation in such a plant as *Fucus*. Eventually a mature plant is produced which may again form gametes.

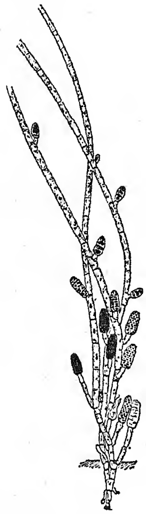


FIG. 201. *Ectocarpus.* (From Oltmanns, *Morphologie und Biologie der Algen*, Gustav Fischer, Jena.)

158. Ectocarpus.—There are many other algae resembling *Fucus* in their brown color, but differing greatly in shape and size. They are collectively known as the brown algae or *Phaeophyceae.* The alga called *Ectocarpus* has a filamentous thallus consisting of one or several rows of cells. The filaments are branched and the entire plant consists of a tuft of such branches attached by its base to a rock or other object. The reproduction is somewhat similar to that of *Ulothrix.* Zoöspores are formed by the division of the protoplasts of special cells—sporangia—which usually project from the main branches of the thallus. Gametes also are formed similarly in special cells, and resemble the zoöspores in appearance but not in function; two gametes unite before development begins. Both the zoöspore (after coming to rest) and the zygote, which results from the union of two gametes, may develop into new filamentous thalli.

159. Other Brown Algae.—Certain other brown algae attain enormous sizes and are commonly known as kelps. They are used as commercial sources for iodine. One of them is *Laminaria*, the body of which consists of a single long blade, which tapers at one end into a stipe attached by a holdfast to a rock or other support; the blade may reach a length of 30 feet. This, however, is a small kelp. *Macrocystis*, another kelp, grows to lengths of 600 feet. It consists of long cylindrical shoots bearing leaf-like blades which float on the surface of the water. Another brown alga of some interest is *Sargassum*, a relative of *Fucus.* It consists of a branched stipe which bears leaf-like blades and berry-like bladders. It is

commonly found floating on the ocean and great masses of it accumulate in that part of the Atlantic known as the Sargasso Sea.

160. **Red Algae.**—Another group of algae, found mostly in the

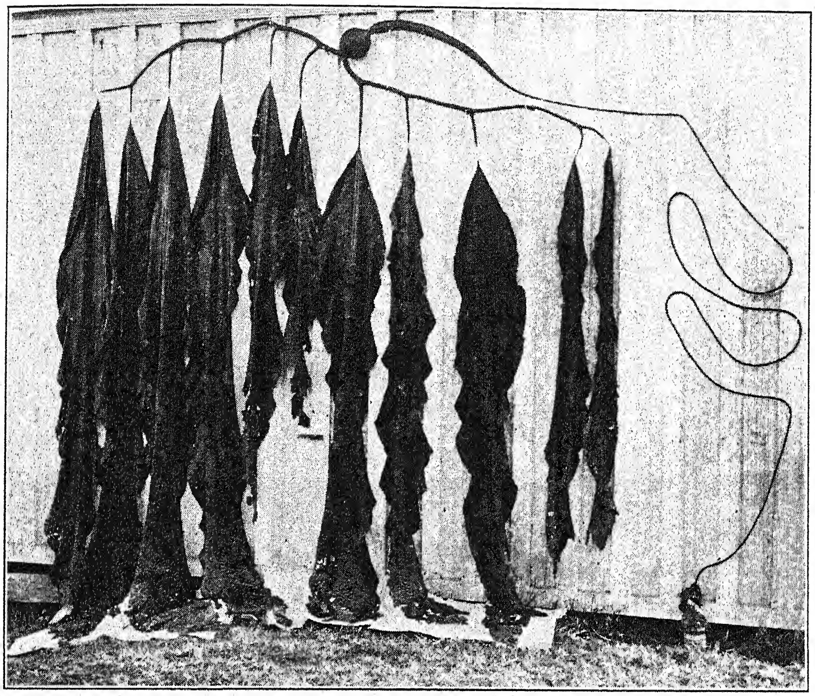


FIG. 202. A large brown alga (*Pelagophycus*) from the California coast. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc. Photograph by courtesy of W. A. Setchell.)

warmer oceans, possesses in addition to chlorophyll a red pigment which masks the green color. These plants are called the *Rhodophyceae*. They differ greatly among themselves in appearance. *Chondrus* is a branched ribbon-like thallus something like *Fucus*. *Grinellia* is composed of several leaf-like thin blades. Many of the red algae, for example *Nemalion*, are composed of branched filaments, and some of these, such as *Polysiphonia* and *Dasya*, are much branched and feathery in appearance. The graceful and delicate appearance of these finely branched structures and their bright color make them objects of great beauty.

161. Summary of the Algae.—The algae, as is evident from the examples we have discussed, are chiefly aquatic, some living in fresh water and others in salt water. Some few kinds, such as

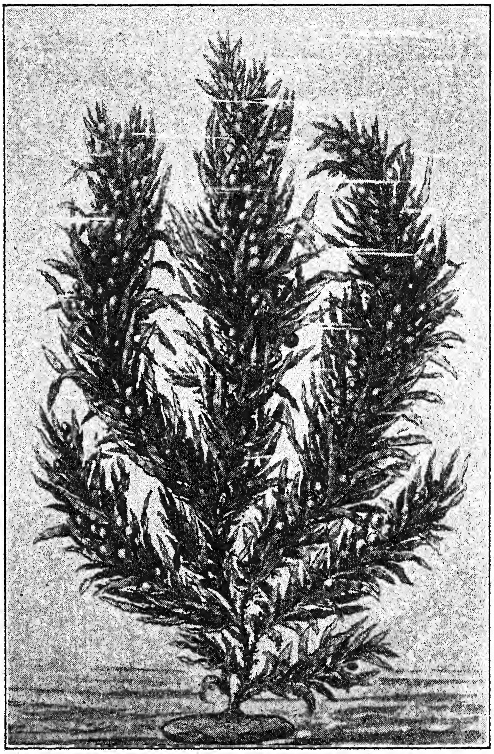


FIG. 203. *Sargassum linifolium.* ×1/2. (From Oltmanns, *Morphologie und Biologie der Algen*, Gustav Fischer, Jena.)

Irish moss (*Chondrus crispus*) and *Gelidia* (from which agar agar is secured), are used as food for man; from others fertilizer salts or iodine are secured. Their chief economic importance, however, is that they are the basic food for fish. Upon the freely floating microscopic forms, called *phyto-plankton*, depends the greater part of the animal life of the oceans and fresh water lakes and streams.

A comparison of the different kinds of algae described above yields a clear demonstration of the meaning and results of differentiation. If, when a cell divides, and its daughter cells redivide, no differentiation occurs, a colony of one-celled individuals results.

The colony may be temporary or permanent, and its form is dependent upon the planes of successive cell divisions. *Protococcus* and *Spirogyra* and their relatives illustrate such colonies. If the daughter cells, or some of them, differentiate, so that one comes to

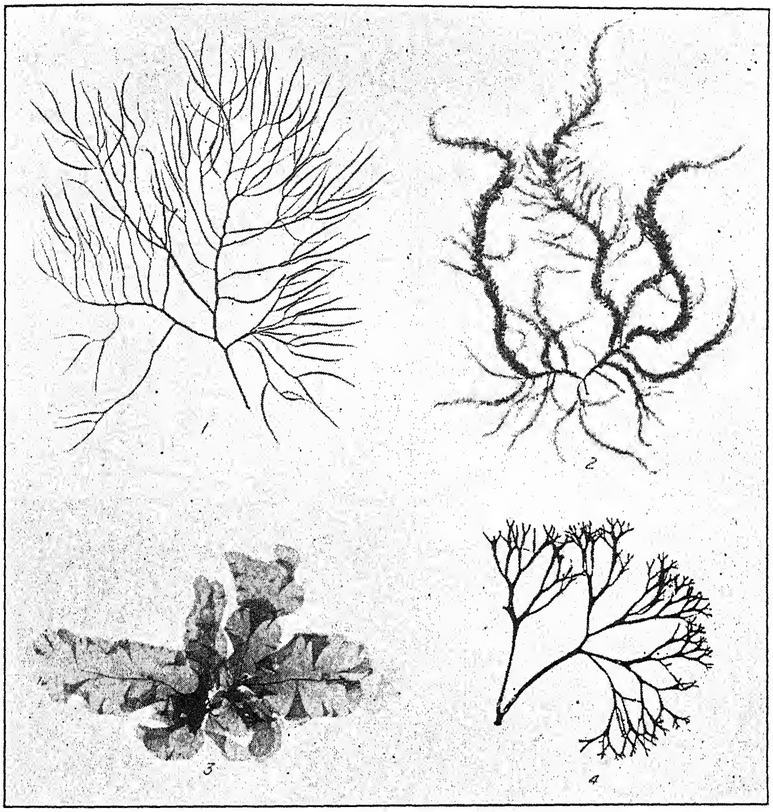


FIG. 204. Four red algae. *1*, *Agardhiella tenera; 2*, *Dasya elegans; 3*, *Grinellia americana; 4*, *Chondrus crispus.* $\times 1/3$. (Photographs of herbarium specimens by Naylor.)

perform functions different from those of another, and the functions of the whole mass of cells comprise many such specialized functions, then a many-celled individual is the result. *Oedogonium* illustrates this to a slight extent, *Vaucheria* is more markedly differentiated, and the red and brown algae are clearly many-celled highly differentiated plants.

162. Summary of the Thallophytes.—The Thallophytes compose a group of plants which is of wonderful variety in form and habit of living and one which is of great importance to mankind. Because of the enormous variety of plants of all kinds that exists on the earth it is necessary to classify them, placing in one group and under one name a large number of plants which resemble each other in some characteristic or group of characteristics which we

FIG. 205. A lichen; old man's beard, *Usnea barbata.* (From Marshall, *Mosses and Lichens*, Doubleday, Page & Co.)

select. The Thallophytes include in such an artificial group all plants lacking stems, roots and leaves in all parts of their life cycles. It is necessary further to subdivide this large and varied group into two classes, the algae, which possess chlorophyll, and the fungi, which lack chlorophyll. These classes, again, are too large to handle conveniently, and the plants within each are assembled

into still smaller classes; for instance, the Ascomycetes and the Rhodophyceae. Even these classes are very large and include large differences among their members; so that they are subdivided into orders and families (not named or discussed in this book), and the

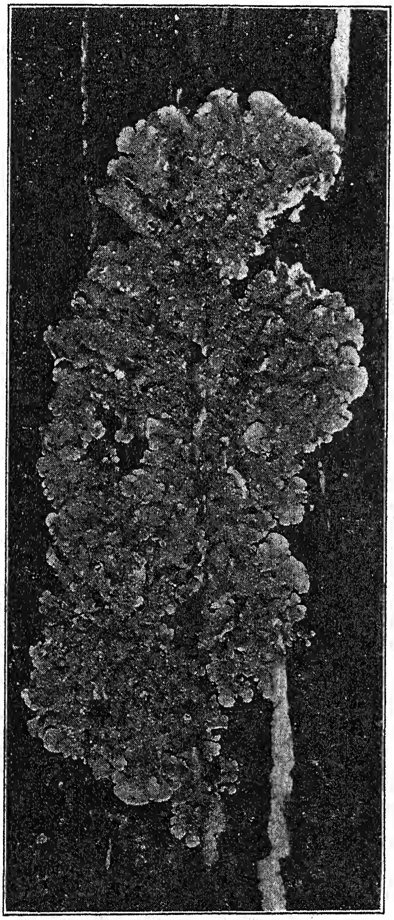


FIG. 206. A lichen, *Ricasolia amplissima*, on hickory.

families in turn into genera and species. The species are the distinct types of plants, a few of which have been here described. The following diagram will make clear the classification of the Thallophytes.

- Thallophytes
  - Fungi
    - Bacteria
    - Myxomycetes
    - Phycomycetes
    - Ascomycetes
    - Basidiomycetes
    - Fungi Imperfecti
  - Algae
    - Myxophyceae
    - Chlorophyceae (and Diatoms)
    - Flagellata
    - Phaeophyceae
    - Rhodophyceae

163. **Lichens.**—Besides all the classes enumerated above, among the Thallophytes are some very interesting plants known as lichens. These are classified neither among the fungi nor among the algae; and it is misleading to include them as a third distinct group;

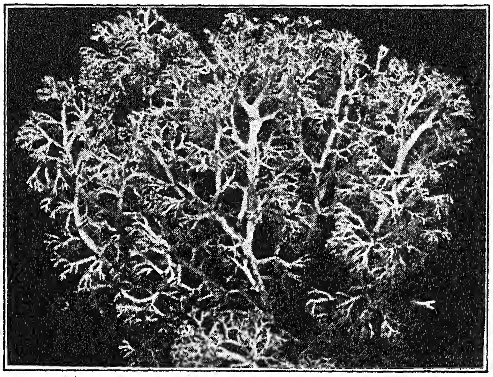


Fig. 207. A lichen; reindeer moss, *Cladonia rangiferina*. (From Smith, *Lichens*, Cambridge University Press.)

for a lichen is made up of a fungus and an alga growing together in one plant body and forming one individual. The thalli which result from such associations are of various forms according to the kinds of fungi and algae involved. Some lichens are much branched structures that hang pendent from the branches of trees (they are *epiphytes*, not parasites). Others are somewhat leaf-like, being composed of large fleshy lobes which lie flat on the ground. Still others form minute scaly incrustations on rocks and on the bark of trees. Internally these thalli consist of fungous mycelia, in the meshes of which are algal cells; the latter compose, in many kinds

of lichens, a distinct layer near the upper surface and parallel to it. In most kinds of lichens the fungus is an Ascomycete, and forms outgrowths somewhat resembling the sporophores of the cup fungus; the inner surfaces of these cups are lined with asci containing ascospores. The spores, when they germinate, will form a new

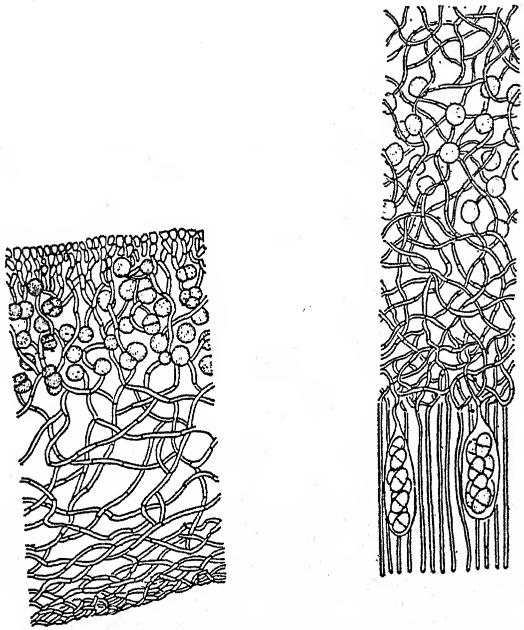


FIG. 208. Sections through lichens showing fungous hyphae and algae. The fungus in the right-hand figure is an Ascomycete. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

lichen only if they encounter cells of the alga. The algae are usually single-celled and somewhat resemble *Protococcus*. The lichens also reproduce by means of bodies called *soredia*, small masses of algal cells enveloped by a few fungous hyphae. These may grow into mature lichen thalli.

Apparently the association of the two kinds of plant in each thallus is a benefit to both of them. The alga manufactures food, some of which is absorbed by the fungus, the fungus protects the alga against mechanical injury and against evaporation, and absorbs water through certain of its hyphae. Lichens are remark-

able chiefly for the extreme conditions which they can endure unharmed. They grow usually on exposed dry rocks and on tree trunks where other plants are not able to obtain sufficient water for life. In the far north, where vegetation is scanty, the lichens compose a considerable proportion of the plant life, and one kind, the so-called reindeer moss (which is not a moss), is used as food by animals, occasionally even by man.

CHAPTER XIX

The Ferns

Bacteria, yeasts, molds, mildews, mushrooms, *Spirogyra*, seaweeds, and such plants have, as we have seen, one common feature, though differing greatly in others: they all lack true leaves, stems, and roots (although they may be complex in other ways). We have grouped them, for the sake of convenience, under the term Thallophytes. Ferns, on the other hand, possess true leaves,

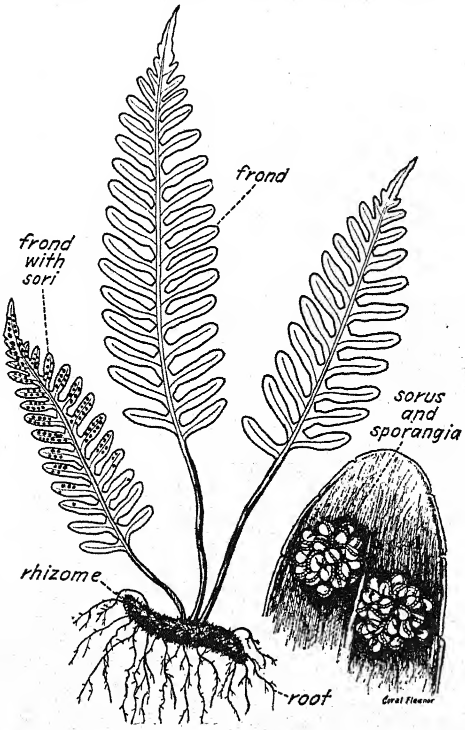


Fig. 209. *Polypodium vulgare.* Left, entire plant; right, tip of pinna enlarged showing two sori.

stems, and roots, built much like the examples of these organs already studied. They cannot, therefore, be included among the

Thallophytes. They do not, as we shall see, form flowers and seeds, and so cannot be called seed plants. They are included in a group known as the *Pteridophytes*, of which the distinguishing marks will become evident as we proceed.

164. Morphology of a Leafy Fern Plant.—What we ordinarily see of the common ferns of temperate countries is the leaves—usually large, much lobed or divided, often feathery in appearance. The stem of such ferns is underground and horizontal, grows at one end and produces new groups of leaves every year. From the stem grow also narrow wiry roots.

If we study a cross section of the underground stem (an underground stem is known as a *rhizome*), we notice at once that it is made up of many different sorts of tissues. There is a marginal layer of epidermal cells with heavy walls. Immediately beneath these are several rows of thick-walled supporting cells. The bulk of the interior of the stem is made up of parenchyma cells, known

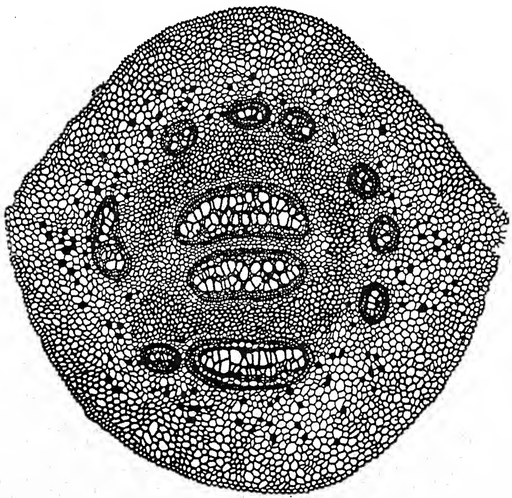


FIG. 210. Cross section of the rhizome of a fern (*Pteris aquilina*), showing the distribution of fibro-vascular bundles. ×10. (From Jeffrey, *Anatomy of Woody Plants*, University of Chicago Press.)

as fundamental parenchyma. Near the center of the section are found two or more sometimes more masses of heavy-walled cells, which are known as internal supporting cells. Scattered throughout the stem, both in a ring around the internal supporting cells and between

the latter, are numerous small fibro-vascular bundles, each possessing pericycle, xylem and phloem and surrounded by an endodermis. The endodermis is a single layer of thick-walled cells.

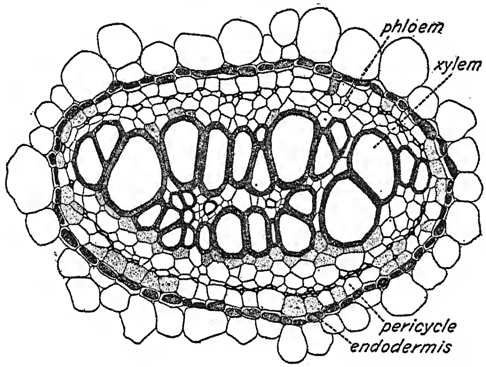


FIG. 211. Cross section of a single fibro-vascular bundle of a fern, *Pteris aquilina.*

The pericycle is also a single layer of cells, each rather square in shape, and often containing starch grains. Within this is the phloem, which entirely surrounds the xylem. The phloem is composed of fibers (phloem fibers) and sieve tubes, with perhaps some parenchyma cells; but the companion cells found in the sunflower are lacking. There is no cambium between phloem and xylem. The xylem is composed mainly of large thick-walled cells which look in cross section exactly like vessels. In longitudinal section, however, it is found that these are not formed from rows of cells whose end walls disappear. They are tracheids (pines and related seed plants also lack vessels). There may also be a few parenchyma cells in the xylem. Because of the lack of cambium, the stem does not become thicker after the above tissues have matured, as does a sunflower stem. Continuous increase of size occurs only in length. The stem is often covered by the bases of the leaves, which in most

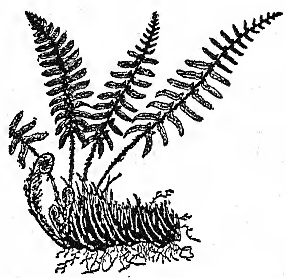


FIG. 212. The Christmas fern, *Polystichum.* Young leaves uncoiling at the bud end of the stem; fully developed leaves of the past season farther back; the older portion of the rhizome covered with the petioles of leaves that have died. (From Curtis, *Nature and Development of Plants,* Henry Holt & Co.)

kinds of ferns remain attached after the aërial parts of the leaves have fallen, and which are often broad and scale-like.

It is evident from this description that the fern rhizome is essentially the same sort of an organ as is the sunflower stem. It contains in the main the same sorts of cells, which function in the same way. The difference is in the details of arrangement.

The structure of the leaves also is similar to that of the leaf previously studied. They possess epidermis with guard cells and stomata, veins (vascular bundles), and mesophyll; the latter, however, is not usually differentiated into palisade and spongy layers. The epidermis is often not heavily cutinized, and most kinds of ferns transpire water rather rapidly. Consequently most kinds of ferns do not usually thrive in dry regions or in very bright sunlight. However, the cliff brake (*Pellaea atropurpurea*) grows in fissures of limestone cliffs; the tree polypody (*Polypodium polypodioides*, see Fig. 11) grows on trunks of trees; and the common brake or bracken (*Pteris aquilina*) often forms thickets on dry hillsides. The roots, though small, are, like the stems, in general similar to the corresponding organs of seed plants.

Most of the activities of ferns are very similar to those already studied in the seed plants. Photosynthesis, respiration, translocation of food, conduction of water, absorption of water, digestion, transpiration, and so forth, need not be here discussed. We are here particularly concerned with their methods of reproduction and with the life cycle.

165. Vegetative Reproduction.—Ferns have a variety of methods of vegetative reproduction. The rhizomes may live many years in the soil, growing and branching. The growth occurs at one end, as in upright stems. The other end frequently dies. When the part of a stem dies from which two branches have originated, then the branches become separate individuals, and vegetative reproduction has occurred.

Some ferns also form on their leaves small masses of cells, known as *bulbils*, which fall off, and, if they fall on moist soil, develop into mature plants like the parent. Here vegetative reproduction occurs by means of specialized structures; but the cells composing these structures are similar to ordinary vegetative cells. Hence we cannot speak of the bulbils as spores.

One fern has this curious property: the leaves are very long and taper to a fine point; this point usually droops and touches the

FIG. 213. Vegetative reproduction by ferns. *1*, a frond of *Cystopteris bulbifera* with bulbils; *2*, *3*, germinating bulbils; *4*, plants of the walking fern, *Camptosorus rhizophyllus*. (*2* and *3* after Matonschek from Bower, *The Ferns*, Cambridge University Press.)

soil; when this happens, a new plant develops from the leaf tip—the latter subsequently disappearing. From this method of reproduction this fern derives its common name of "walking fern." Other kinds of ferns also reproduce by rooting of tips of the leaves.

166. Spores, Sporangia and Sporophylls.—On the under sides of the leaves of most common ferns are found, at certain times in the year, small brown or orange spots, sometimes partially covered by scale-like plates of cells. When viewed under a lens, these spots are found to consist of a number of tiny globular objects on stalks, growing in a cluster from the surface of the leaf. If we scrape off some of these globular bodies and study them with a microscope, we find each to consist of a stalk and a sac inside which are numerous small oval cells; and under appropriate conditions, after being discharged from the sac, these small oval cells grow into new plants. They are therefore spores, and the globular

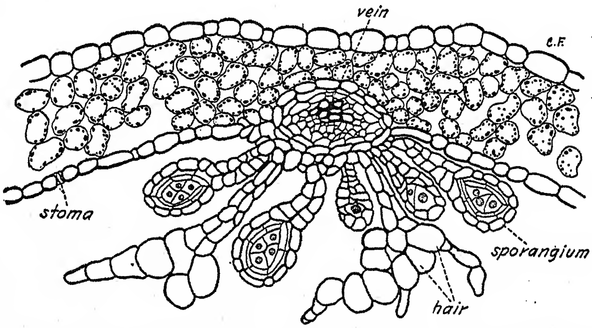


FIG. 214. Section through leaf and sorus of *Polypodium* showing sporangia in various stages of development.

sacs in which they are formed are sporangia. Each group of sporangia (that is, each of the brown or orange spots on the leaf) is called a *sorus* (plural, *sori*). The entire leaf which produces spores is known as a *sporophyll.*

Each sporangium develops from a single cell of the leaf by an orderly series of cell divisions and by the differentiation of the resulting cells. At maturity it consists of a stalk composed of several rows of elongated cells; and an ovoid sac composed of a single layer of cells of irregular shapes. These wall cells are transparent, and through them may easily be seen the mass of rather thick-walled spores inside. One row of cells belonging to the

sporangium wall has a curious structure. Its cells are very thick-walled on three sides and thin-walled on a fourth, which is the outer side. This row of cells, which is called the *annulus*,

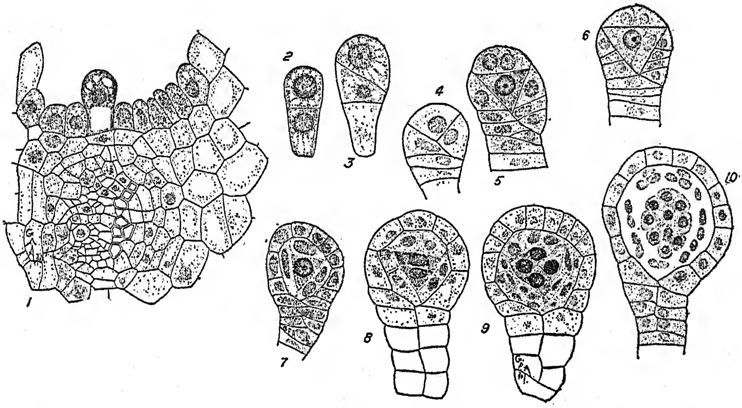


FIG. 215. Development of fern sporangium. *1*, an epidermal cell elongating; *2*, the epidermal cell has divided; *3*, *4*, further division; *5*, cells which will form stalk; sporangium wall and sporangium contents are visible; *6*, *7*, further division and differentiation; *8*, *9*, stalk, sporangium wall, tapetum cells and sporogenous cells are differentiated; *10*, sporangium almost mature, the spores formed, the tapetum disintegrating. (From Atkinson, *The Biology of the Ferns*, copyright 1894 by The Macmillan Company. Reprinted by permission.)

extends about three-fourths of the way around the sporangium. When the cells of the annulus become dry, the whole annulus tends to straighten out, pulling apart, as it does so, the wall cells; later it may snap back with considerable violence, throwing the spores out. In some kinds of ferns the annulus has a structure and arrangement different from that here described.

167. Formation of Spores and Reductional Division.—The spores are formed by the division of certain cells within the sporangium which are therefore known as *spore mother cells*. Each spore mother cell undergoes a nuclear division and each of the two nuclei formed divides again, forming a total of four nuclei. When these divisions are studied carefully it is found that in the first of these divisions whole chromosomes (instead of half-chromosomes) move to the two poles and each of the daughter nuclei has half as many chromosomes as were present in the nucleus of the spore mother cell. This special type of mitosis is called *reductional*

division, since after its completion each daughter nucleus possesses a number smaller than that originally in the mother nucleus. If the number of chromosomes in the spore mother cell is assumed

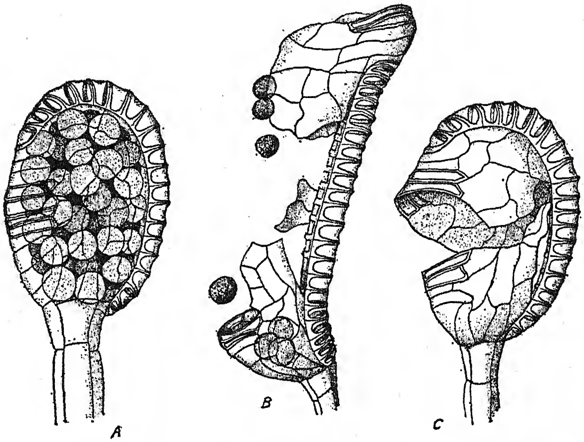


FIG. 216. Fern sporangia. *A*, unopened sporangium filled with spores; *B*, the annulus has straightened and torn the sporangium wall into two halves, freeing the spores; *C*, the empty sporangium after the annulus has returned to its first position.

to be $2x$, that in each daughter nucleus would be x. The $2x$ chromosome number is frequently called the *diploid* or double number and the x the *haploid* or single number. The divisions of the two daughter nuclei are equational divisions, in which the number of chromosomes is not further reduced and each of the four nuclei (like the two mother nuclei) contains the x or haploid number. After the four nuclei have been formed, cell walls develop between them. The four cells thus formed become the spores.[1]

Since reductional division occurs at this point, each spore nucleus contains one-half the number of chromosomes originally present in the nucleus of the spore mother cell. The spore mother cells, like all other cells of the body of the fern, are descended by ordinary equational mitosis from the cell from which the whole plant body developed; and since equational mitosis maintains in each nucleus the same number of chromosomes, the same number will be found in all the cells of the stems, roots, and leaves of the fern. In other words, the whole plant that we have been discussing is a diploid structure.

[1] At first they are united in groups of four; such a group of four spores is known as a *spore tetrad*.

168. Reproduction by Spores.—The fact that this plant reproduces by means of spores, and never by means of gametes, is indicated by calling it a *sporophyte*—spore-bearing plant. With the exception of some of the brown and red algae, the term sporophyte is used only in groups other than the Thallophytes.

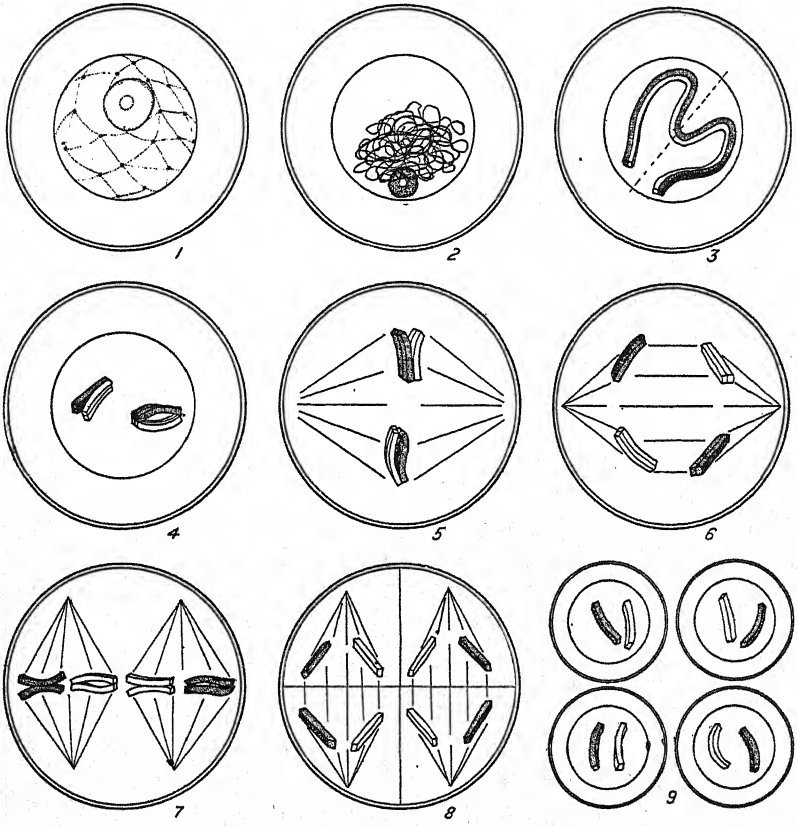


FIG. 217. Diagrams of reductional division in the development of fern spores. For simplicity the diploid number of chromosomes is assumed to be four. *1*, resting stage of spore mother cell; *2*, the chromatin has formed into a thread which contracts to one side of the nuclear cavity (this condition is known as *synizesis*); *3*, the thread thickens and shortens and segments into chromosomes, which occur in pairs; *4*, the four chromosomes, in two pairs, each split longitudinally; *5*, *6*, whole chromosomes separate and move to the poles, one of each pair to opposite poles; *7*, reductional division is complete, equational division begins; *8*, the halves of each chromosome separate; *9*, four spores each containing two chromosomes result. (Redrawn from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

The spores possess fairly heavy walls and some stored food, and may live for a long time in a dry condition. When, however, they encounter moisture and the other conditions which bring about growth, the wall cracks, and the protoplasmic contents protrude through the opening, thus commencing growth. A cell

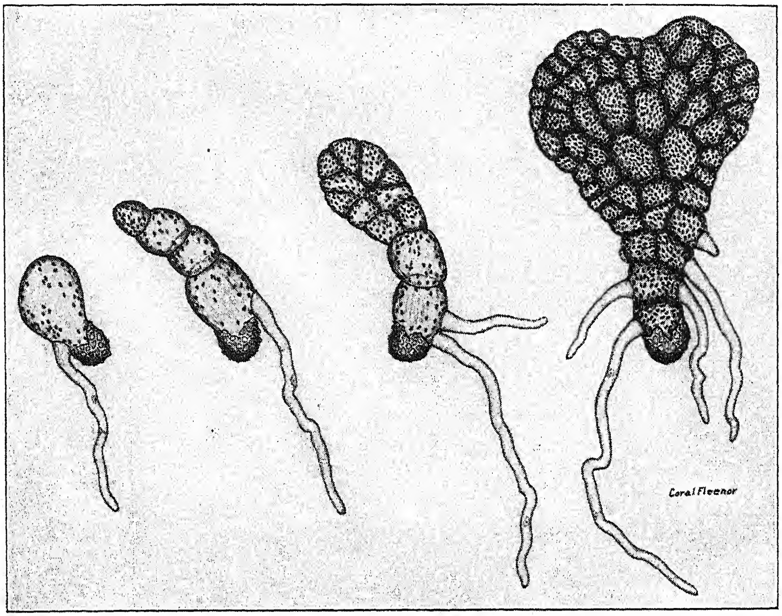


FIG. 218. Stages in the growth of the fern gametophyte.

division occurs very soon, and at once, usually, differentiation becomes evident; for the cell next to the old spore wall has little chlorophyll, and sends out a long narrow protrusion known as a rhizoid (compare the rhizoids of *Rhizopus*), which penetrates the substrate and functions in much the same way as do the root hairs of the seed plants. The remaining cell contains much chlorophyll. It continues development, forming first a filament of green cells. Then walls are formed at right angles to those previously formed, later walls at various angles appear, and a flat plate of cells is the result. Certain cells develop rhizoids like the first one formed. This plate becomes gradually larger. A group of cells at one side remains embryonic; the cells which they form on each side enlarge rapidly, thus forming lobes with a deep notch

between them. The whole plant may thus become somewhat heart-shaped, though its form is influenced by the presence of other plants or objects and is frequently irregular. The plant may become several cells thick in the middle, and may attain a size of half an inch in diameter. This is the mature stage of the plant which develops from the spore. It is haploid, because the spore from which it developed was haploid, and only equational divisions are involved in its growth. Every nucleus in this plant contains the x number of chromosomes.

Since this plant has no leaves, stems, or roots, it must be called a thallus. It is of course just as truly a fern plant as the large leafy structure commonly known as a fern—since it is descended

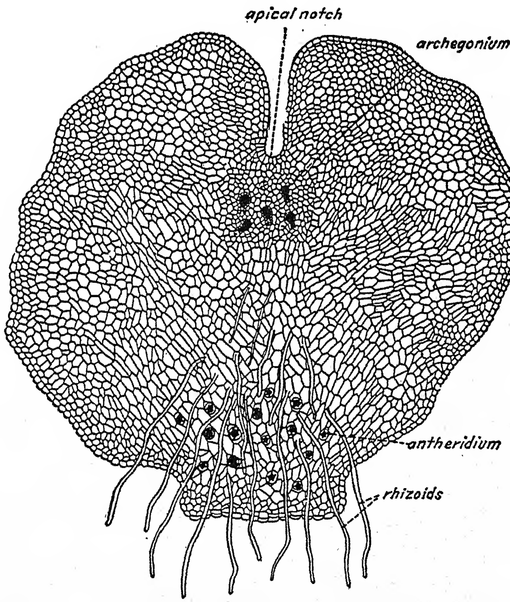


FIG. 219. Mature fern gametophyte, seen from the under side. ×12. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

by reproduction from that sort of plant. Evidently we have two distinct kinds of mature individuals which we may call ferns, both being the same species. The thallus of a fern is often known as a *prothallus* (plural, *prothalli*).[2]

[2] Or *prothallium*.

169. Gametes and the Gametophyte.—When we study the method of reproduction of this thallus we find that cells are produced by it which unite, and the product of their union develops into a new mature sporophyte. In other words, the thallus reproduces by means of gametes, and not by spores. It is called therefore a *gametophyte*—gamete-bearing plant. Two sorts of gametes are formed, differing in size, form, and function, which, on account of the difference in size, may be called megagamete and microgamete.

On young thalli small spherical bodies may be observed, usually on the under side near the point of the thallus where the rhizoids are most abundant, but often in other places. Each of these consists of a jacket of transparent cells, inside which, at maturity, may be seen a large number of very tiny cells. The structure is known as an *antheridium*. Eventually the jacket breaks, and the tiny cells inside are discharged into the surrounding water (fern thalli usually grow only in moist places, where there is a film of moisture often present on the soil; if this is lacking, gametic union

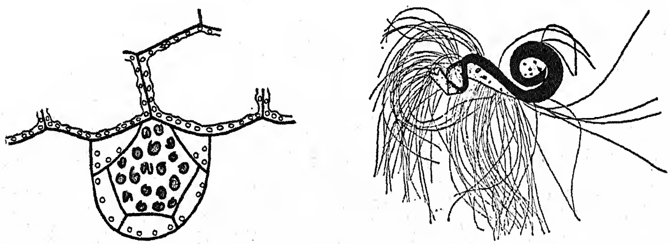


Fig. 220. Left, a single fern antheridium seen from the side. Right, a single microgamete. (Right-hand figure from Steil in Botanical Gazette.)

cannot take place). Each of these cells is an elongated structure at first tightly coiled up. Shortly after their discharge they partially uncoil and begin to move about in the water very rapidly and erratically. A stained preparation of one of these bodies shows that it is composed mainly of a long narrow nucleus enveloped by a thin sheath of cytoplasm. There is no cell wall. From one end of this spirally shaped cell many very delicate threads of cytoplasm protrude. They are called flagella, and are similar in structure and function to the flagella of the bacteria. It is because of their activity that the cell moves. These motile cells are the microgametes. They are produced in great numbers, and the water surrounding a fern thallus may swarm with these tiny swimming creatures, moving in all directions.

As the thalli become older, other bodies are produced which contain the megagametes. They are called *archegonia* (singular, *archegonium*). Each consists of a jacket of cells embedded in the tissues of the thallus itself, just next its lower surface. In the center of this jacket (technically known as the *venter*) is a single large oval megagamete. From the venter projects a sort of curved chimney, consisting of several parallel rows of cells, which extends

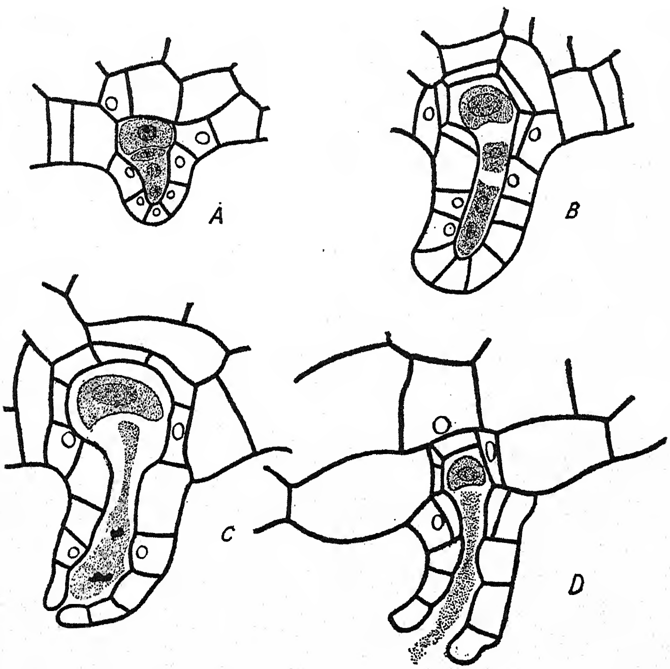


FIG. 221. Fern archegonia. *A*, young archegonium; *B*, more mature archegonium in which the canal cells are about to disintegrate; *C*, mature archegonium about to open; the canal cells have disintegrated; *D*, mature archegonium open and ready for fertilization.

out from the surface of the thallus. When the archegonium is mature the central row of cells in this projection—which is called the *neck*—dies and disintegrates, thus forming a passageway (*neck canal*) from the megagamete to the outside world. The gamete is, however, far too large to be discharged through this opening, and it lacks the power of motion.

170. **Gametic Reproduction.**—If a young thallus is near an

older thallus, the water surrounding both may contain an abundance of swimming microgametes produced by the younger. Some of these will probably come into the vicinity of the necks of the archegonia of the older. These turn and swim down the canal of the neck into the venter, and one of them—probably the first to arrive—unites with the megagamete in the venter. Experimental evidence indicates that some sort of substance, perhaps malic acid, is produced in the archegonium which stimulates the microgamete to swim towards it. Frequently a large number of microgametes enters the archegonium, though only one unites with the megagamete to form the zygote; the others die.

Two facts stand out in this history: Gametic union is dependent upon the presence of water, just as it is in many of the algae. And the union of the gametes takes place *within the tissues of one of the parent plants.* The zygote begins its growth immediately, and obtains the necessary food and water from the parent by which it is surrounded. The offspring of the fern thallus is thus, during the first part of its life, a *parasite upon its parent.*

Each gamete contains the x (haploid) number of chromosomes, since it developed from the spore by a series of equational divisions. When two gametes unite, the chromosomes do not lose their identity, and the zygote therefore contains the $2x$ (diploid) number of chromosomes, x from each gamete.

171. Growth of Zygote.—The zygote divides first into two, then into four cells. Each of these cells then divides into many cells, which differentiate. Of the four groups of cells formed, one gradually develops into a mass which penetrates up into the body of the parent, and absorbs nourishment from the latter. This is called a *foot.* A second develops into a little root—a true root, not a rhizoid—which penetrates the soil. A third becomes a small leaf, which curls up around the edge of the thallus, often through the notch, becomes exposed to air and light, and commences the manufacture of food. From this time on, the young plant, though still attached by its foot to the parent plant, is manufacturing its own food from materials absorbed by it from the air and from the soil, and is no longer entirely parasitic. Other small leaves and roots may be developed from the bases of the ones first formed. Finally the fourth group of cells develops into a stem, which grows slightly downwards and then horizontally beneath the surface of the soil, and is therefore a rhizome. From this stem large leaves

develop, identical in every way with those of the fern sporophyte studied above; and additional roots develop. The primary leaves and roots, the foot, and the parent plant (the gametophyte) in

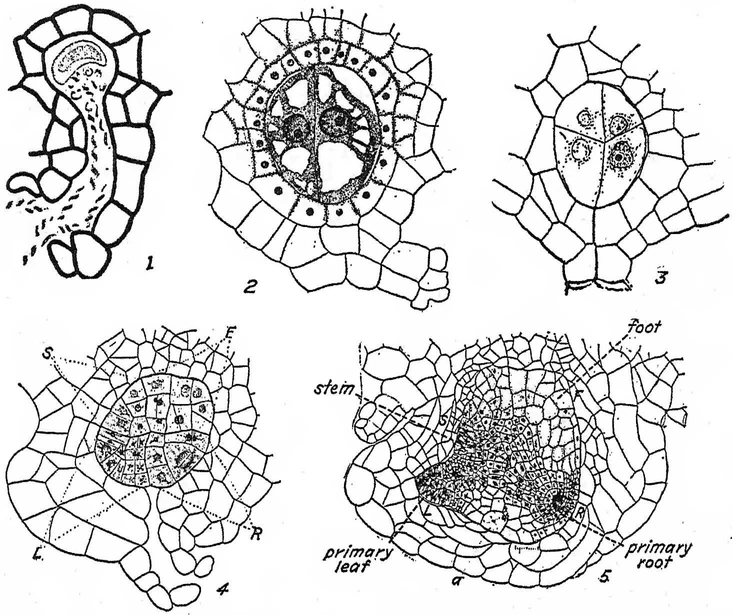


FIG. 222. Stages in the formation of the embryo sporophyte of a fern. *1*, fertilization, microgametes in the canal of the archegonium; *2*, zygote divided to form two-celled sporophyte; *3*, four-celled sporophyte; *4*, many-celled sporophyte; the progeny of each of the four cells in the preceding figure can be identified; *5*, the progeny of each of the cells of the four-celled stage forms one of the four parts of the young sporophyte, foot, primary root, primary leaf, or stem. The embryo is still surrounded by the venter of the archegonium. (*1* after Shaw in the Annals of Botany; *2*, *4*, *5* from Atkinson, *The Biology of Ferns*, copyright 1894 by The Macmillan Company; reprinted by permission; *3* from Campbell, *Structure and Development of the Mosses and Ferns*, copyright 1905 by The Macmillan Company; reprinted by permission.)

which the foot is still anchored, finally die, and there remains a mature leafy fern plant, which was developed from the stem produced from the zygote. Doubling of chromosome number occurred when the gametes united; the zygote is a diploid cell. And since the cell divisions that occur during development are all equational, the entire plant developed from the zygote is diploid; just like the leafy plant with which this life history started.

172. **Alternation of Generations.**—It is evident that there are

two sorts of fern plants, related by reproduction. One is diploid, possesses leaves, stems, and roots, and is a sporophyte; the other, which results from the reproduction of the first, is haploid, a

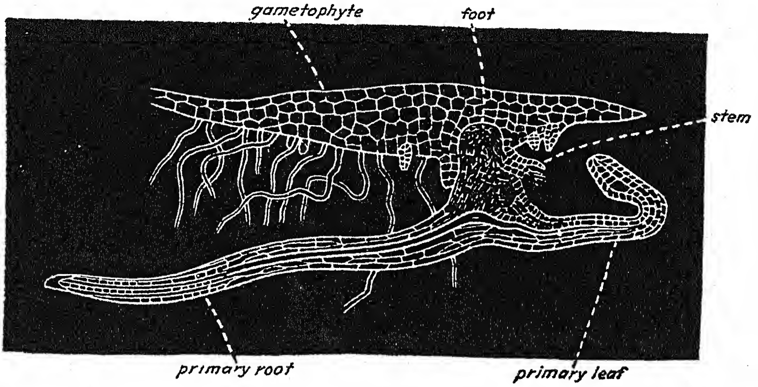


FIG. 223. Section through fern gametophyte and young sporophyte which is still attached by its foot to the gametophyte. (From Warming, *Systematic Botany*, copyright 1895 by The Macmillan Company. Reprinted by permission.)

thallus, and a gametophyte; its reproduction, in turn, produces the sporophyte. This is an interesting illustration of the fact that a plant may have an inheritance—protoplasm—derived from its

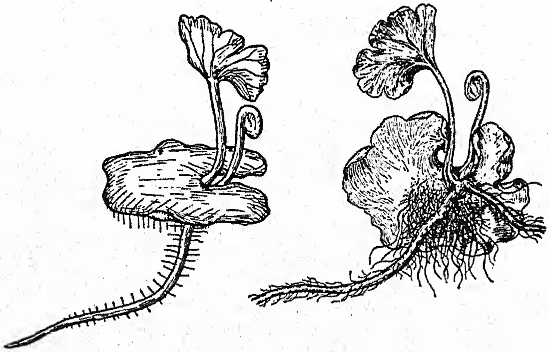


FIG. 224. Left, view of upper surface of fern gametophyte and young sporophyte; right, another gametophyte and sporophyte seen from below. (Right-hand figure from Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

parent, and yet have an entirely different appearance. Also it illustrates the meanings of the terms reproduction and life cycle;

each type of plant, sporophyte and gametophyte, is an *individual* derived from the development of some of the protoplasm of the preceding plant or plants—and the formation of a new individual is reproduction. And these different sorts of individuals both

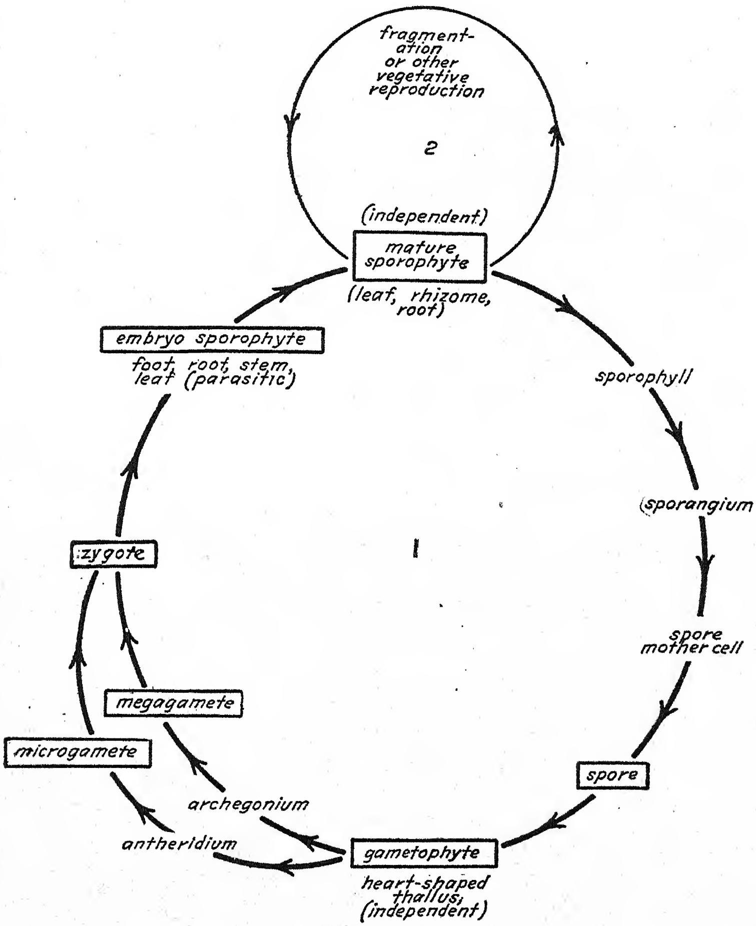


FIG. 225. Diagram of the life-cycle of a fern.

belong to the same species of plants, both have essentially the same sort of protoplasm, since they give rise to one another; they illustrate the life cycle of that kind of plant.

This sort of a life cycle, which includes two forms of the same

sort of plant, one haploid and a gametophyte, the other diploid and a sporophyte, is of the greatest importance, because it is the type of life cycle found in all plants other than the Thallophytes, and in some of the Thallophytes also. The two types of plant, sporophyte and gametophyte, are known as *generations*, and the

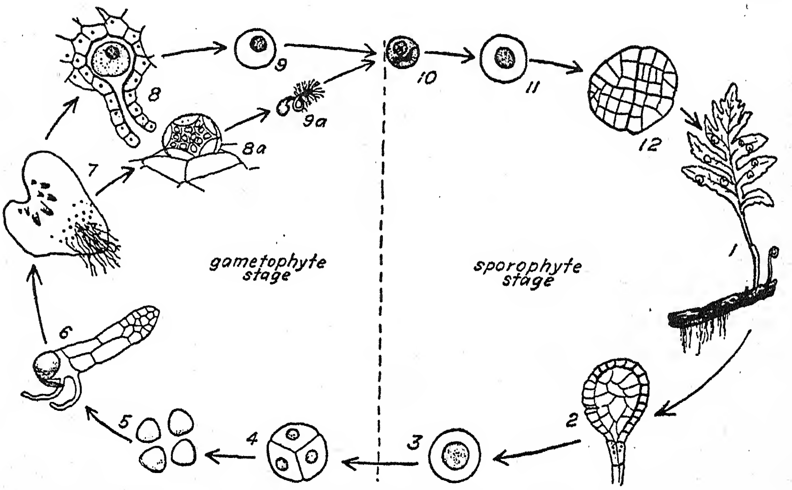


Fig. 226. Diagram of the life-cycle of a fern. (After Schaffner from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

fact that one is always developed from the other is spoken of as the *alternation of generations*.

Summarizing, we see that the fern differs from the Thallophytes in complexity of structure and specialization of functions; in these respects the fern resembles the seed plants, such as the sunflower or buttercup. One of its generations is, to be sure, a thallus; but the other consists of complex leaves, stems, and roots. Gametes are formed in specialized many-celled containers, the antheridia and archegonia; structures called antheridia are found in some Thallophytes, but differ from those of the fern in not being many-celled; and nothing resembling an archegonium is found in any Thallophyte. In its alternation of generations the fern resembles the groups of plants which will be discussed later. Most Thallophytes, though they include haploid and diploid plants in their life cycles (whenever they reproduce gametically), have no well marked gametophyte and sporophyte generations.

However, while we may point out these features which we use to distinguish the ferns as a group we must not forget that essentially life is the same thing here as elsewhere. The essential processes—digestion, respiration, growth—occur in ferns as in Thallophytes and in other plants. And reproduction, while it differs greatly in

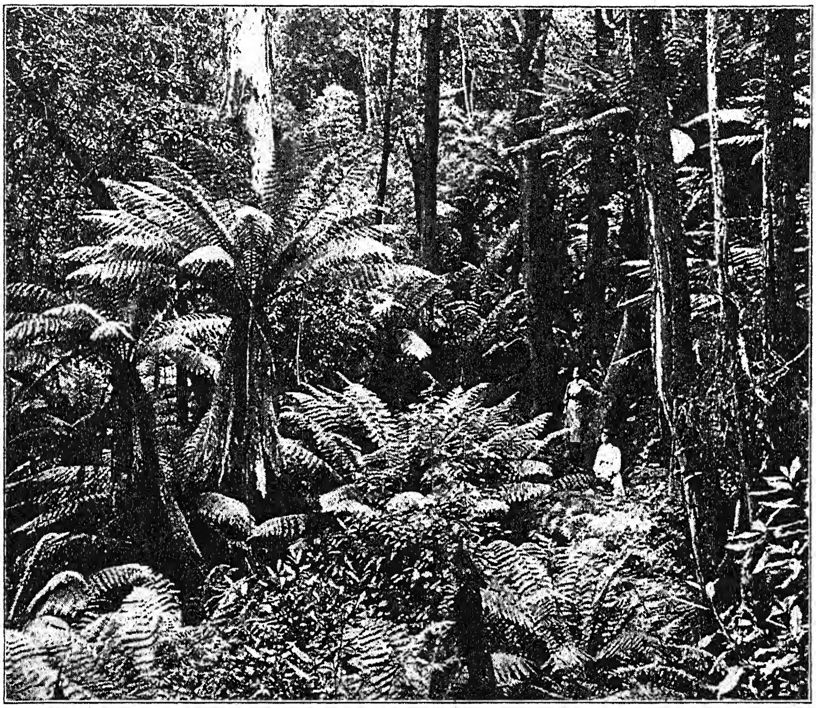


FIG. 227. Tree ferns in a New Zealand forest. (Copyright National Geographic Society. Reproduced by special permission from the National Geographic Magazine.)

detail in these different groups of plants, is fundamentally the same process in all. Spores and gametes, and larger groups of cells which develop into new individuals, are found in all groups of plants.

173. The Variety of Kinds of Ferns.—Ferns, because of various peculiarities of structure and function, thrive usually in moist shady regions. In this country they are found most abundantly in shaded ravines along the banks of streams, and under dense forests where the air is apt to be moist. As has been already

mentioned, many kinds grow also on open hillsides, and in other dry places, and can tolerate dry conditions (see Figs. 371 and 372). In tropical countries where there is an abundance of rain, and where vegetation is rich and the ground consequently well shaded, ferns grow very luxuriantly, and some of them reach great size. Some have upright stems which extend above the soil and produce crowns of leaves at their tips. Some of these upright ferns attain heights of thirty or forty feet and are known as tree ferns. The leaves are often of enormous size. Other kinds grow attached to the trunks

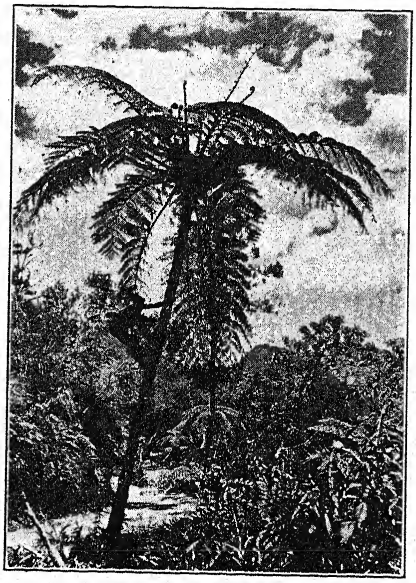


FIG. 228. A tree fern. (Copyright National Geographic Society. Reproduced by special permission from the National Geographic Magazine.)

of trees. They do not secure their food from the trees, and cannot therefore be called parasites; they are attached to the bark, absorb water which is present on this bark in moist weather, and manufacture their own food. Such plants (there are also plants in the other groups which live in the same way) are called *epiphytes*.

The kinds of ferns differ greatly in the size, number, arrangement, and structure of the sori. The sorus is sometimes partially covered or enclosed by a scale-like or sac-like outgrowth from the leaf called an *indusium* (plural, *indusia*). The indusia of the bladder-

fern (*Cystopteris*) are sacs; those of the shield-fern (*Aspidium*) are shield-shaped, attached by a short stalk; the sori of maidenhair (*Adiantum*) and of bracken (*Pteris*) are on the margin of the leaf and covered by the inrolled edge of the leaf. The sporophylls of some kinds of ferns are identical in appearance with the vegetative

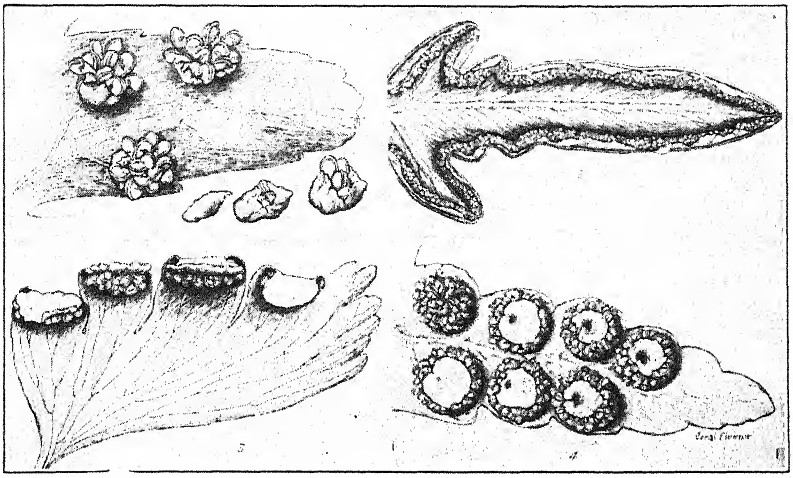


FIG. 229. Sori of various ferns. *1*, bladder fern, *Cystopteris; 2*, bracken, *Pteris; 3*, maidenhair, *Adiantum; 4*, shield fern, *Aspidium*.

leaves. In some species (for example the cliff brake) the sporophylls are smaller than the vegetative leaves. In the interrupted fern (*Osmunda Claytoniana*) and some other species, certain pinnae of the sporophyll are spore-bearing and differ greatly in appearance from the purely vegetative parts of the same leaf. In still other kinds, for example the sensitive fern (*Onoclea sensibilis*), the entire sporophyll is quite different from the vegetative leaves, being covered by sporangia and having no flat blade.

174. Fossil Ferns.—Except in the tropics and a few other places, ferns are not the most familiar objects of our landscapes. Most of the plants we commonly see are seed plants, such as oaks, elms, grasses, geraniums. We have evidence, however, that it was otherwise in past times. This evidence is derived from fossils.

Fossils (literally things "dug up" out of the earth) are formed in two ways. A plant or part of a plant may become surrounded by, imbedded in, rock in the process of formation, which therefore

FIG. 230. Fronds of various ferns. *1*, interrupted fern, *Osmunda; 2*, maiden-hair, *Adiantum; 3*, sensitive fern, *Onoclea; 4*, sporophyll of *Onoclea; 5*, a portion of a frond of bracken, *Pteris*.

bears the imprint of the plant long after the latter has disappeared. These are incrustations or casts; they make known to us, of course, only the external appearance of the plant. Under certain circumstances, the particles which compose a plant may be gradually replaced by particles which become rock, so that a rock is formed

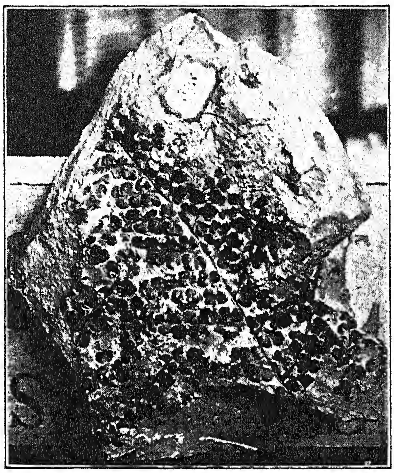


FIG. 231. A fossil fern. (Copyright National Geographic Society. Reproduced by special permission from the National Geographic Magazine.)

which reproduces the entire structure of the plant, even to the cells and the interior structures of the cells. These are called petrifactions. Rocks containing petrifactions can be ground down to plates of minute thickness and studied under the microscope as are prepared sections of plant tissues. In this way we can get a very accurate idea of the plants that existed when the rock was formed.

Fossils are found frequently in layers of rock which were formed many thousands of years ago. By examining these fossils, therefore, we can gain some idea of the appearance and structure of at least some of the vegetation which existed in those far-off days. Of course, there must also have been many other types of vegetation which did not happen to be so preserved, or which, if preserved, have been obliterated by subsequent changes in the rocks.

From such evidence it appears that many thousands of years ago, in the period known to geologists as the Devonian, the ferns and their relatives formed a far larger proportion of the flora than

did seed plants similar in type to our familiar trees, garden flowers, and so forth. There were ferns similar to those of to-day, and many, including giant ferns and tree ferns, which no longer exist. Later in the Carboniferous (coal-bearing) ages, there were still many ferns; there was also an abundance of fern-like plants which formed seeds, the so-called seed-ferns.

Ferns therefore, as we know them to-day, are but a relic of a once proud race. Many kinds have become extinct; and the large ones are restricted to the tropical parts of the earth's surface. The seed ferns have totally disappeared. The place of both the ancient ferns and the seed-ferns is taken by the seed plants we see around us to-day.[3]

[3] A comparison of the life cycle of the fern with that of *Spirogyra* serves to show that the differences between the two are not so great as might appear at first sight. The kind of *Spirogyra* plant which gives rise to gametes, and which therefore corresponds in its reproduction to the fern gametophyte, is haploid in chromatin content, and the gametes also which are formed are haploid. The zygote, as in the fern, is diploid. In *Spirogyra* the zygote undergoes the reductional division, so that the product of its germination is again a haploid plant. But in the fern the zygote develops by means of equational division, so that the diploid number of chromosomes is retained in each cell; and the result is a many-celled diploid plant body, to which there is nothing corresponding in *Spirogyra*. This diploid body of the fern then reproduces by means of spores, in the formation of which reductional division occurs, and the spores are thus haploid cells, and develop by equational divisions into haploid plants again.

In *Fucus*, the chromosome number is doubled in the formation of the zygote, and the zygote develops by equational divisions to form the dichotomously branched *Fucus* plant. Each cell of the holdfast, stipe and flattened branches has, therefore, the $2x$ number of chromosomes. The uninucleate antheridium and uninucleate oögonium are diploid. Of the 63 nuclear divisions which occur in the development of the 64 microgametes in the antheridium the first is reductional and the others equational. Each microgamete is therefore haploid. Of the 7 nuclear divisions which occur in the development of the 8 megagametes in the oögonium the first is reductional and the others equational. Each megagamete is therefore haploid.

In *Rhizopus* it is thought that the chromosome number is doubled when the gametes unite, and that the reductional division occurs just before spores are formed by the dwarf mycelium, which grows from the zygote. The spores and the mycelia produced from them are haploid; the zygote and dwarf mycelium diploid.

Judging from those living things which have been examined, a reductional division occurs in the majority of organisms which reproduce gametically. Therefore there is in such organisms an alternation of the haploid and diploid conditions, though some of them may have no sporophyte or gametophyte generation. The number of equational divisions which the zygote undergoes before reductional division takes place and the number of equational divisions which the first formed haploid cells undergo before gametic union occurs determine the extensiveness of the diploid and haploid forms. It is evident that if reductional division did not occur continued gametic reproduction would result, in a few generations, in cells each containing innumerable chromosomes.

CHAPTER XX

Bryophytes

For various reasons, which will appear later, certain small plants are classed neither as Thallophytes, nor as Pteridophytes, nor as seed plants, but form a group in themselves which we call the Bryophytes—"Moss Plants." They include the mosses and the liverworts.

Mosses

175. General Morphology and Physiology.—Mosses are diminutive leafy plants which appear to the casual glance like a mat of

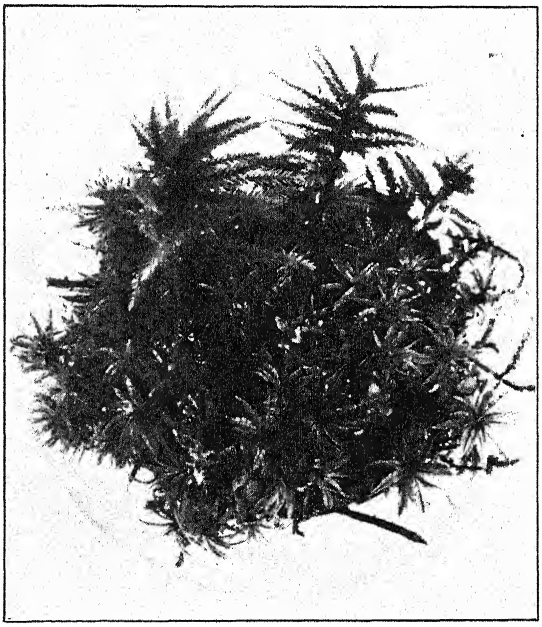


Fig. 232. A group of moss plants. The taller tree-like moss is *Climacium;* the other is *Catharinea.* Natural size.

green wool. Bacon described them as "something between putrescence and a plant." They are among the most successful and

universal plants known. Different kinds occupy all sorts of situations—dry soil, marshes, fallen trees, the bark of living trees (see Fig. 372),[1] rocks, running water—even the bottoms of lakes, twenty feet beneath the surface. Scarcely any part of the earth that will support plants at all is altogether without mosses. There are several reasons for this wide distribution. The plants are small, require little anchorage, and, since they are usually erect, little ground space (wherein they have a decided advantage over such plants as liverworts, which lie flat on the substrate). They reproduce vegetatively, producing new plants in all directions, and thus forming often a close mat of small plants which holds moisture

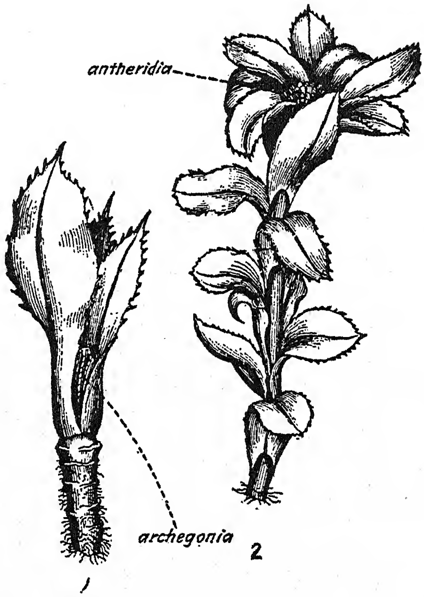


FIG. 233. Moss plants showing the location of archegonia and antheridia and the difference in arrangement of leaves at the stem tips of archegonial (*1*) and antheridial (*2*) plants. Several leaves have been removed from the archegonial plant. (From Grout after *Bryologia Europea.*)

well. And, finally, they can endure extraordinary extremes of climate, though apparently without special structures adapted to such endurance. In northern countries they are covered during winter by many feet of snow; they may often be seen frozen in solid masses of ice; yet in the spring, when ice and snow disappear,

[1] Some mosses are therefore epiphytes.

they resume growth uninjured. In regions such as the western United States, where there is a season of heavy rainfall alternating with a very dry season, mosses grow abundantly. In summer they may be seen, for instance, on the branches of trees, curled up, crisp, and apparently dry and dead (Fig. 372). When rain comes, they absorb water, uncurl, and resume growth.

The plant body consists of a small stem bearing simple leaves. These parts do not resemble the true stems and leaves of seed plants except in shape; they have no highly differentiated vascular system, no spongy parenchyma nor stomata. The stems have an epidermis, sometimes some supporting cells, and, in the center, often some elongated cells which serve for conduction. The rest is parenchyma and undifferentiated. The leaves of most mosses are single layers of cells, sometimes with a midrib of a group of elongated conductive cells. In some kinds of mosses (for instance *Polytrichum*, sometimes called "hairy cap" or "pigeon wheat") there are *lamellae* (singular, *lamella*) or plates of cells extending from the surface of the leaf; this of course increases the area in which gases can be interchanged with the air, and so provides a fairly efficient apparatus for photosynthesis.

FIG. 234. *A*, a moss, *Tetraphis*, showing gemmae (*g*); *G*, a gemma enlarged. (From Gager, *General Botany*, P. Blakiston's Son & Co.)

Mosses vary greatly in size. Some are so minute that a mass of them appears like green velvet; the leaves can scarcely be seen without a lens. Others (such as *Mnium*, a moss common in moist woods) have a stem an inch or more long, and broad leaves. In some tropical countries there are giant mosses reaching a height of many inches.

Mosses have no roots, but, instead, filaments of cells, called rhizoids, which perform most of the functions of roots. These arise from the lower parts of the stems.

176. Vegetative Reproduction.—Some mosses form on their stems certain small specialized bodies called *gemmae* (singular, *gemma*), small masses of cells which become detached by the splashing of raindrops or similar agencies, and develop into new mature moss plants. This then is a method of vegetative reproduction. The gemmae cannot be called spores since, though they are bodies specialized in form, their cells resemble the ordinary vegetative cells of the plant.

177. Gametic Reproduction.—In many mosses, for example *Mnium*, there are two sorts of leafy plants. One kind has the leaves widely spread apart at the tip of the stem, exposing the end of the latter and forming a sort of small disc or cup around it. The other kind has its leaves folded closely together as in an ordinary vegetative bud of a seed plant, the tip of the stem being covered.

On the summit of the first kind of branch mentioned, antheridia are formed, growing from the end of the stem. They are essentially like the antheridia of a fern, except in being long and narrow instead of dome-shaped, and in being attached to the stem of the moss by a short stalk. Each consists of a wall, formed of a layer of cells, enclosing many microgametes. When mature, if they are covered with water (as often happens to such small plants, through

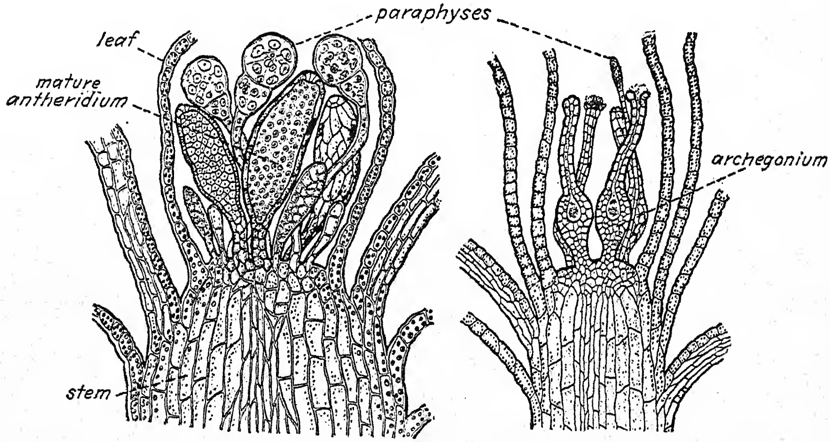


FIG. 235. Longitudinal sections of apices of stems of moss plants bearing archegonia or antheridia. Left, antheridia in various stages of development; right, archegonia. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

rain or dew or the overflowing of a stream), the wall bursts and the microgametes emerge and swim around in great numbers in the water. In structure they resemble the microgametes of a fern, being thread-like coiled bodies; but each possesses only two flagella instead of many. Mixed with the antheridia on the end of the stem are many hairs, composed of filaments or plates of cells, often of odd shapes. These are known as paraphyses.[2]

[2] Compare with the paraphyses of *Fucus* and *Agaricus*.

On the other sort of leafy branch, also growing from the end of the stem, but closely enveloped by leaves, are archegonia. Each consists of a neck and venter, as does that of a fern. The venter contains a single megagamete, and the central row of cells in the neck disintegrates and forms a canal leading to this gamete from the outside. The archegonia are not embedded in the vegetative cells, like those of a fern, but stand out from the end of the stem on rather long stalks. They are much longer and narrower bodies than fern archegonia. Paraphyses are found mixed with them, as with the antheridia.

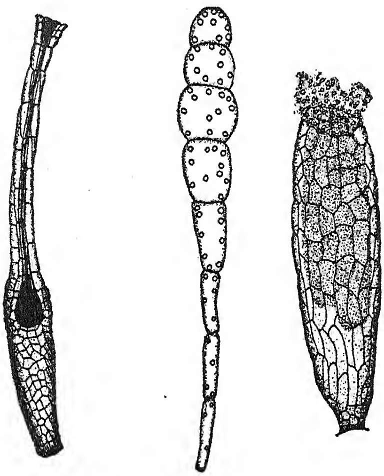


FIG. 236. Left, a single archegonium of a moss (*Mnium*); center, a sterile hair (paraphysis) associated with the antheridia; right, a single antheridium discharging the microgametes.

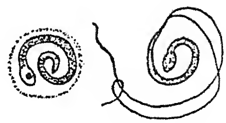


FIG. 237. Microgametes of a moss. Left, microgamete still enveloped in mucilaginous remains of mother cell wall. Right, microgamete fully developed and motile. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

Union of gametes takes place exactly as in a fern. The microgametes are discharged into water surrounding the plants. Such as chance to come near archegonia pass down the neck-canals (the canal cells having disintegrated), possibly in response to some substance which comes from the archegonium. The gametes unite in the venter of the archegonium, and the new individual begins life completely enveloped by a tissue of its parent.

178. The Development of the Sporophyte.—The zygote thus formed immediately develops, like that of a fern, parasitically, sending a mass of cells into the top of the stem of its parent, and at the same time growing upwards at the other end. At first the archegonium also enlarges, so that it continues to enclose the new

plant. Finally, however, the latter grows too fast for the venter, breaks it off near the base, and carries it up with it as a cap. The enlarged remains of the archegonium now form what is called the *calyptra*. The zygote finally develops into a slender leafless body, consisting of a long *stalk*, anchored by the *foot* embedded in the

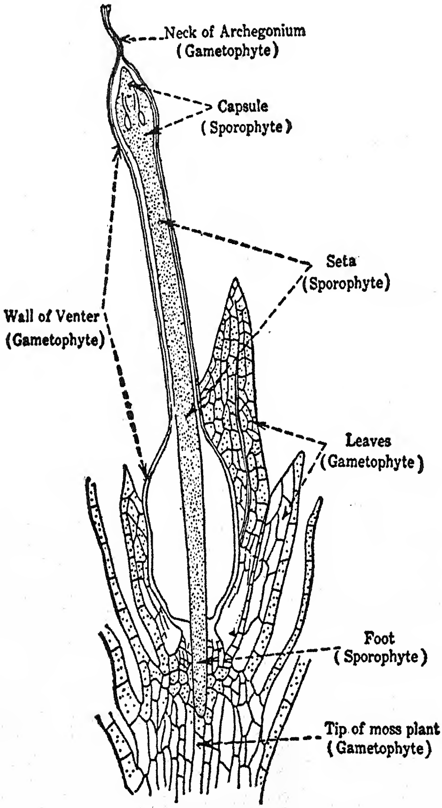


FIG. 238. A young moss sporophyte still enclosed in the enlarged archegonium. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

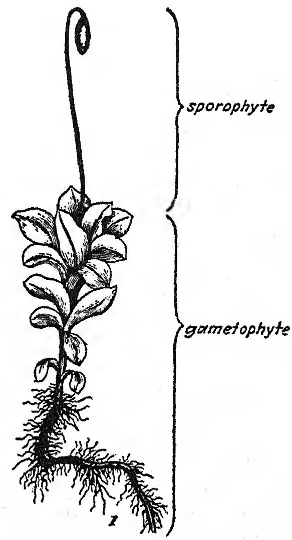


FIG. 239. A single gametophyte and sporophyte of a moss, *Mnium*. (From Grout after *Bryologia Europea*.)

gametophyte, and bearing on its upper end a more or less ovoid body, the *capsule*. Within the capsule spores are formed from spore mother cells by reductional divisions—just as in the sporangia of a fern. This body is therefore the sporophyte generation of a

moss—a separate plant, the offspring of the leafy plant, although parasitic upon the latter. Since it was formed by a union of gametes, and develops by equational mitosis, it is a diploid plant, while the leafy plant is haploid. And since the haploid reproduced by gametes it is a gametophyte; the diploid being the sporophyte. So we have an alternation of generations just as in the fern, the differences being, first, that the gametophyte is a leafy plant (though of a very simple type); second, that the sporophyte is a thallus, forms no roots, stems, or leaves; third, that this sporophyte not only begins its life as a parasite upon its parent, as does that of a fern, but *remains so all its life.*

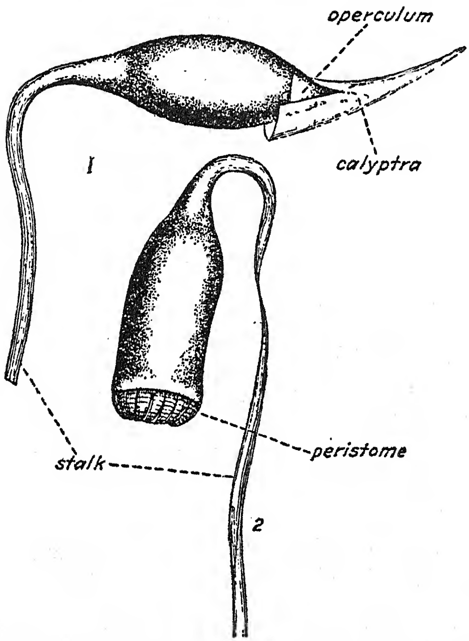


FIG. 240. Capsules of a moss, *Mnium rostratum*. *1*, with calyptra and operculum; *2*, calyptra and operculum removed so as to show the peristome. (From Grout after *Bryologia Europea*.)

The sporophyte is such a small and inconspicuous plant that one is tempted to forget altogether that it is an individual plant, and to look upon it as merely a part, an organ, of the gametophyte. It is, however, just as much a product of gametic union as the fern sporophyte. And if the product of a gametic union in the Pterido-

phytes and in the Thallophytes is an individual, we must continue to regard it as such in the Bryophytes, small and parasitic though it is. The little sporophyte growing from the tip of a leafy moss shoot is just as much a moss plant as is the green leafy plant. And its tissues, though partially embedded in the leafy plant, are sharply distinct from the latter.

Although the sporophyte is externally a very simple thallus, there is considerable internal differentiation in the capsule. The mature capsule is frequently covered by the enlarged calyptra, which in *Polytrichum* bears a dense fringe of white hairs at its base. In *Mnium* and other mosses the calyptra is smaller and falls off before the capsule is mature. (The calyptra is of course not a part of the sporophyte.) At the tip of the capsule of most kinds of mosses is a flat or conical lid—*operculum*—which falls off when the capsule is ripe. Beneath the lid is usually a circle, or often

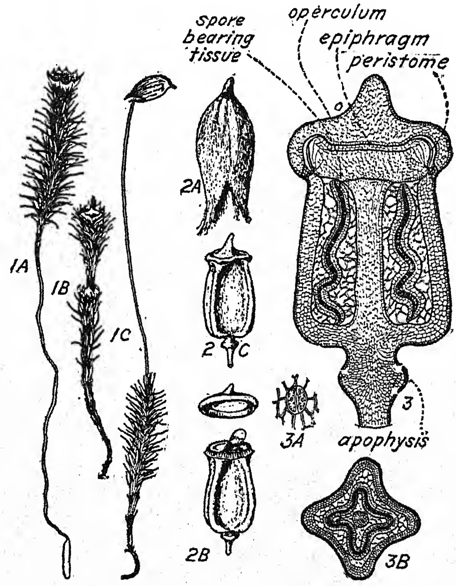


FIG. 241. Hairy-cap moss, *Polytrichum*. *1A*, gametophyte with antheridia; *1B*, same in which the upper end of the stem has renewed its growth (proliferated); *1C*, archegonial gametophyte and sporophyte; *2A*, calyptra; *2B*, capsule with operculum removed and edge of epiphragm lifted above the peristome; *2C*, capsule, unopened; *3*, longitudinal section through capsule; *3A*, stoma from the apophysis; *3B*, cross section of capsule. (*1A*, *1B*, *1C* from Gager, *General Botany*, P. Blakiston's Son & Co.; the others from Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

two circles, of teeth; the whole group of teeth is called the *peristome*. In the interior of the capsule is a *columella*, extending from the base through the center, and surrounding this on all sides is the spore sac, containing many small spores. Between the spore sac and the outer wall of the capsule is at first a photosynthetic tissue composed of filaments of green cells separated by air spaces. The sporophyte varies greatly in different mosses. The peristome is sometimes lacking. In *Polytrichum* the end of the columella is

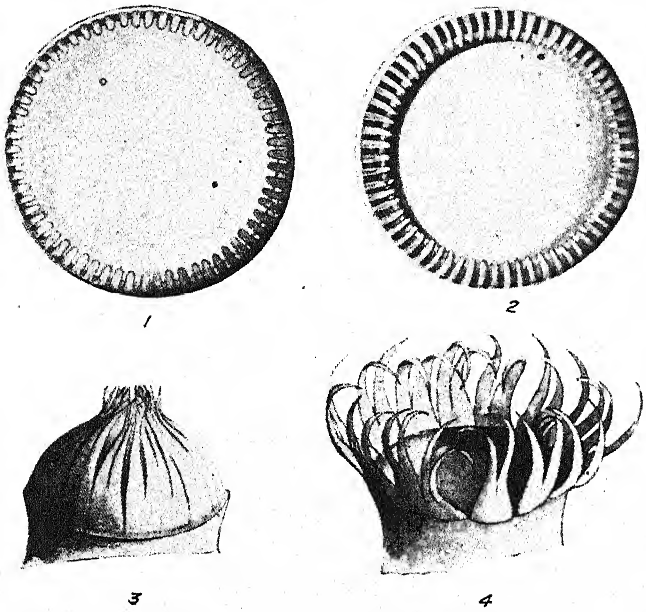


FIG. 242. Action of peristome of moss capsule. *1* and *2*, *Polytrichum ohioense*; *1*, peristome moist, epiphragm swelled, teeth straight, very small openings between; *2*, peristome dry, epiphragm shrunken, teeth bent, leaving spaces between through which spores sift out. *3* and *4*, *Dicranum*; *3*, peristome moist, teeth close capsule; *4*, peristome dry, teeth spread apart, leaving capsule open. (From *Mosses with a Hand Lens* by A. J. Grout, by permission.)

expanded into a plate, the *epiphragm*, which is joined with the teeth at its margin. In some kinds of mosses there are even stomata of the type found in a leaf (a structure, by the way, never found in a gametophyte) connecting the intercellular spaces with the outer air. For a time, therefore, the sporophyte manufactures some food; but even so it may be considered a parasite, since it

absorbs the necessary water and mineral salts from living cells of the gametophyte. At maturity, this photosynthetic tissue withers, the capsule usually becomes brown, the operculum falls off, the spore sac breaks, and the spores sift out beneath the teeth. The teeth control to some extent the dispersal of spores from the capsule; they straighten and bend again with changes in their moisture

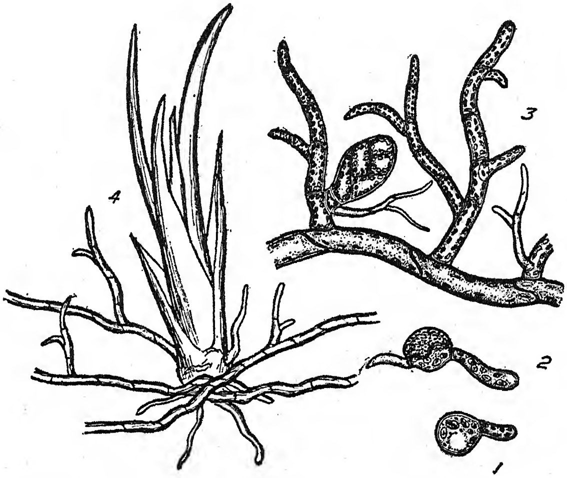


FIG. 243. Germination of moss spore and development of protonema. *1*, *2*, stages in the germination of the spore; *3*, a portion of a protonema with a bud; *4*, a portion of a protonema with young leafy shoot. (*1*, *2* and *3* from Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

content, the spores escaping between them when they are bent outwards. After the spores have been discharged, the whole sporophyte withers away.

179. The Development of the Gametophyte.—The spores, when they encounter abundant moisture and other favorable conditions, begin to grow. Each spore forms one or more tube-like protuberances. These elongate, and crosswise cell divisions occur. This process is repeated until a filament of cells has been formed. Occasionally branches develop. The young plant, which at this stage resembles a filamentous green alga, is called a *protonema* (plural, *protonemata*). Most of the cells contain numerous chloroplasts. Some of the branches, however, penetrate the substrate, are without chlorophyll, and frequently their walls acquire a brown color. These are called rhizoids, and function as do the rhizoids of a fern.

A curious characteristic of the protonema is the occasional occurrence of cross walls not perpendicular to the side walls—oblique walls.

On the protonema small, actively dividing masses of cells are formed which grow into the stems and leaves of the gametophyte. These are known as buds, and grow by means of embryonic regions at their tips in much the same way as do the buds of seed plants. After they have grown into leafy shoots, the protonema often dies; this is of course a method of vegetative reproduction, since several leafy shoots may have arisen from the same protonema and are thus separated. The capacity of mosses for vegetative reproduction is astonishing. Often new protonemata arise from stems or leaves, and on them new leafy shoots are produced; the

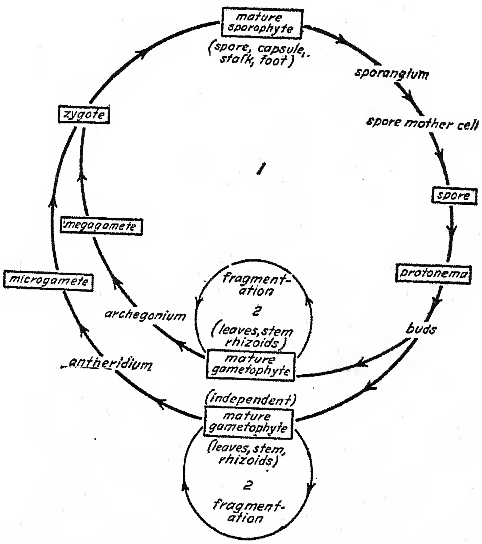


FIG. 244. Diagram of the life-cycle of a moss.

protonemata then dying and the new shoots thus becoming separate plants. If portions of a moss plant are broken off or injured, many of the cells will develop into protonemata and ultimately into new individuals.

With the production of the leafy shoot, the life cycle is complete—we have arrived at our starting point. The general scheme is evidently the same as that of a fern—alternation of generations,

gametic union within an archegonium, production of spores by reductional division. The difference lies chiefly in the nature of the sporophyte—instead of the large, leafy, independent plant of the fern we have a little parasitic thallus, looking like a part of the gametophyte upon which it grows.

Liverworts

Growing on rocks by streams and in the moist soil surrounding springs one may often find small flat green plants, narrow and

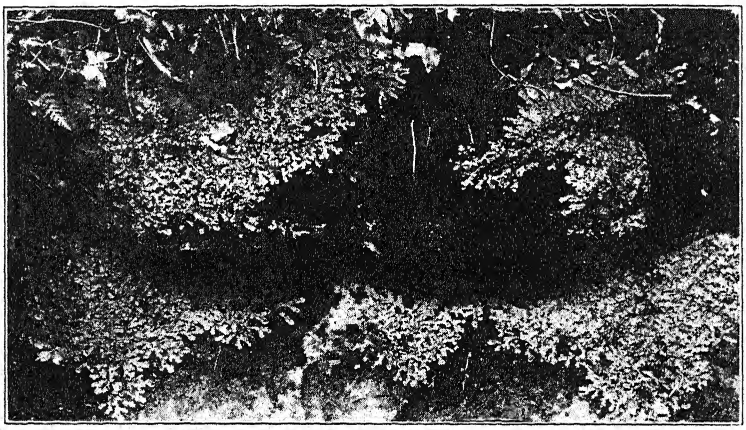


Fig. 244*a*. Liverworts (*Conocephalum conicum*, a relative of *Marchantia*) growing on moist rocky ledges. Mosses (mainly *Entodon*) also are present.

branching, leafless and stemless. These are commonly known as liverworts. Their body is obviously a thallus; at first sight, they, like the gametophyte of a fern, might be classed among the Thallophytes.

In some moist tropical countries, and in other lands—such as the countries of northern Europe—where rain is abundant and the climate damp, liverworts are fairly common. They are found in this country mostly in rocky or mountainous spots near streams or lakes that do not dry up in summer. In much of the country, however, they are rather rare, owing probably to the semi-arid character of the climate in summer.

Many different types of liverworts are known. One of the most familiar is called *Marchantia;* and this will serve as an example of the group.

180. The Gametophyte.—The plant body of *Marchantia* that we usually see is a flat green branching thallus. It grows continually in length but not in width, so that it is often described as "ribbon-shaped"; but this shape is destroyed by the constant branching. The branching is dichotomous; the two branches usually develop

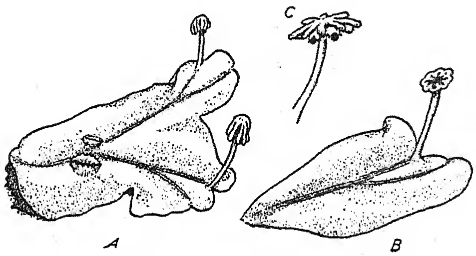


FIG. 245. *Marchantia polymorpha.* *A*, archegonial plant bearing young archegonial branches and cupules; *B*, antheridial plant bearing an antheridial branch; *C*, portion of a mature archegonial branch bearing sporophytes.

about equally, and may themselves branch; and so on. Growth is due to the activity of a small group of embryonic cells[3] at one end.[4] As new cells are formed, enlarge, and differentiate at one end of the thallus, old ones at the other end die. When all the cells die up to a place where the thallus is forked, the two branches become separated and each is an individual plant. This may therefore be called a method of vegetative reproduction. If a single *Marchantia* plant is set in the center of a large box of soil, under conditions favorable to its growth, after a few months the original plant will have disappeared, and instead we shall have a circle of a number of separate plants, all derived from the first by this sort of reproduction.

If the upper surface of the thallus is examined with a lens, it is seen to be marked off into small areas of a rhomboidal shape, each with a tiny hole or pore at the center. These areas are best understood by studying a cross section of the plant. This shows the upper (*dorsal*) surface to be composed of a single layer of cells, beneath which is a layer of air chambers of fairly regular size, separated by vertical layers of cells. It is these air chambers

[3] Perhaps a single cell.

[4] Branching is brought about by the maturation of some of the embryonic cells in the center of the group, so that two groups of embryonic cells are formed from the original group.

beneath the surface layer of cells that cause the little areas apparent on the latter—the partitions between the air chambers, seen from above, forming the lines which bound the rhomboids. The pore at the center of each rhomboid connects the air in the air chamber with that of the outer world. The pore is built like a small chimney of several tiers of cells. From the floor of the chambers arise branching filaments of cells which nearly fill the chambers. The cells of these and of the floors, side-walls and roofs of the chambers contain many chloroplasts and the whole structure constitutes a photosynthetic apparatus something like that of a leaf—palisade layer, spongy tissue, and stomata.

Just below the photosynthetic cells are several layers of large colorless cells, in which food may be stored, and which may therefore be called storage tissue.[5] From the lower (*ventral*) surface of the thallus project rhizoids similar to those of a fern thallus—elongated single cells which anchor the plant to the substrate and absorb water and dissolved substances.[6] Scales also project from the ventral surface, plates of cells one layer thick.

181. Vegetative Reproduction.—*Marchantia* possesses an interesting method of vegetative reproduction in addition to that already described. On the dorsal surface of the thallus little cups—*cupules*—are found, formed of upstanding circular ridges of cells. Within are small disc-like bodies, each standing on edge on a short stalk. These break loose from their stalks rather easily—a splashing rain-drop or a current of water is sufficient to dislodge them and carry them far from the parent plant. They are called gemmae. Each consists of a number of cells, mostly green. Each is several cells thick in the middle. The outline is not quite circular; there are two deep notches on opposite edges, and a more shallow indentation marking the attachment of the stalk. Both surfaces are alike; but when the gemma is detached and washed out on to the soil, growth occurs, the (now) ventral surface differentiates rhizoids and other ventral structures, while the dorsal surface forms air chambers and other dorsal structures. In each of the deep notches are embryonic cells which continue growth in the way typical of *Marchantia*.

182. Gametic Reproduction.—Ordinarily the plants grow flat

[5] Some of these cells contain mucilage.

[6] Some of the rhizoids are marked by peculiar pegs—called tubercles—of material which project inwards from the cell wall.

along the substrate. But, under certain environmental conditions, some of the embryonic cells begin to divide in a different plane and produce branches at the growing end that extend straight up into the air. These branches consist each of two portions: a more or less cylindrical *stalk* and a more or less circular *disc* on top. It is interesting that the stalks may have air chambers along one side and rhizoids and scales along the other, indicating that they are merely branches of the thallus which grew, so to speak, in the "wrong" direction; the scales and rhizoids are of small use thus elevated in the air. The same is true of the discs, which have dorsal and ventral tissues much like those of the main part of the thallus.

These branches are gamete-bearing structures, and may therefore be called *reproductive branches*. The gametes, as in the fern

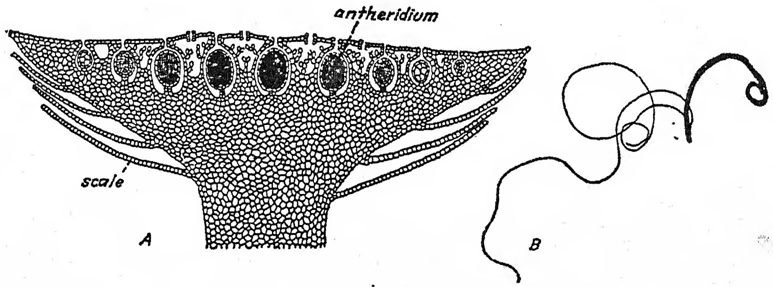


FIG. 246. *A*, section through antheridial disk of *Marchantia; B*, a microgamete. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

and moss, are of two sorts, and are borne in archegonia and antheridia. Each branch bears only one sort of gamete, and hence may be called an antheridial or archegonial branch as the case may be. Furthermore, one plant does not produce both sorts of gametes, as in the fern; the whole plant may therefore be called antheridial or archegonial.

The antheridia are produced on the upper surfaces of the discs. This disc consists of a number of branches or lobes growing out in all directions from the middle; and antheridia are formed in rows on each lobe. The tissues of the disc grow up around the antheridia, so that the latter are sunken in pits, which are connected with the outside by narrow pores. As the first formed antheridia mature near the center of the disc, new ones are being formed nearer the

margin, where growth is taking place; there is therefore a progressive decrease in size and age of antheridia from the center of the disc out in all directions. The antheridium itself is essentially

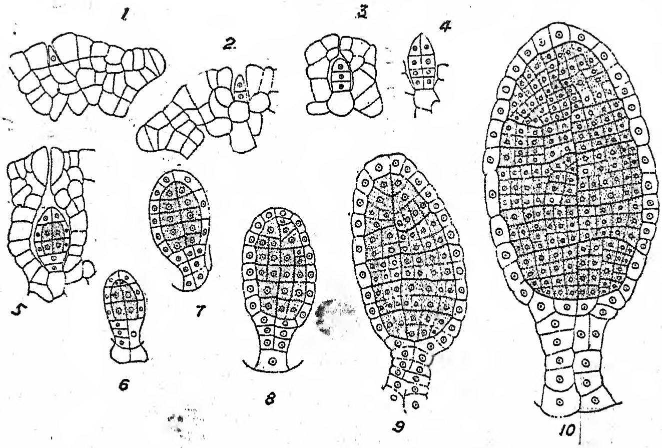


FIG. 247. A series of stages in the development of an antheridium of *Marchantia*. (From Durand in the Bulletin of the Torrey Botanical Club.)

like that of a moss. The microgametes also resemble those of a moss.

Archegonia, like the antheridia, are formed on the upper surfaces of the discs, one row to each lobe, the youngest nearest the margin. But while they are still very young, a rapid enlargement takes place in the dorsal part of the center of the disc, which pushes the growing tissues with the young archegonia into an inverted and reversed position—the archegonia now hang downwards and the youngest one is that nearest the stalk. From what is now the upper surface of the disc, in the notches between the lobes, grow long green cylindrical projections, known as *rays*, which extend out and down like the ribs of a tiny umbrella, giving the archegonial discs an appearance very different from that of the antheridial.

The archegonia, like the antheridia, are essentially the same as the corresponding organs of the moss. The stalk, however, is short. And around the base of the venter is a projecting ring of cells which afterwards develops into a tissue known as the *perianth*. On each side of each row of archegonia hang *curtains*,

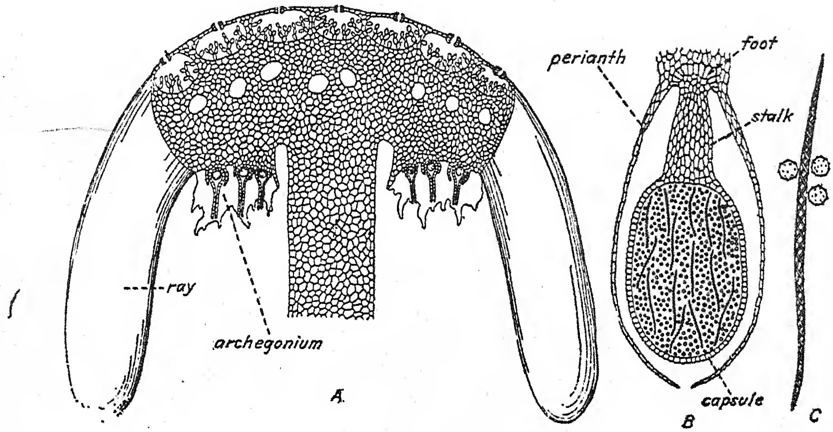


FIG. 248. *A*, section through archegonial reproductive branch of *Marchantia;* *B*, the sporophyte; *C*, an elater and spores. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

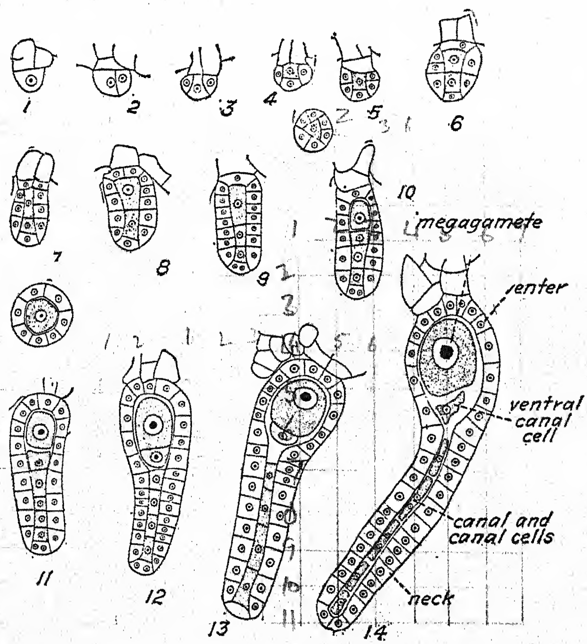


FIG. 249. A series of stages in the development of the archegonium of *Marchantia.* (From Durand in the Bulletin of the Torrey Botanical Club.)

each made of one layer of cells and delicately fringed at the lower edge.

Each archegonium and each antheridium develops, as does the sporangium of a fern, by an orderly series of cell divisions and the differentiation of the cells formed, from an original cell. All organs of plants are results of regular developmental processes, in which cell division and differentiation are involved.

183. **Development of the Sporophyte.**—Union of gametes takes place exactly as in a moss. The gametes unite in the venter of the archegonium, and the new individual, the zygote, starts life as a parasite within its parent's tissues.

In development and mature structure the sporophyte resembles a moss sporophyte. The zygote divides by a transverse wall into two cells, these divide in turn, and the resulting cells divide again, so that an *octant* of eight cells is formed (four are visible in one plane, as in a section). By further series of divisions, the four cells nearest the neck of the archegonium develop into the capsule;

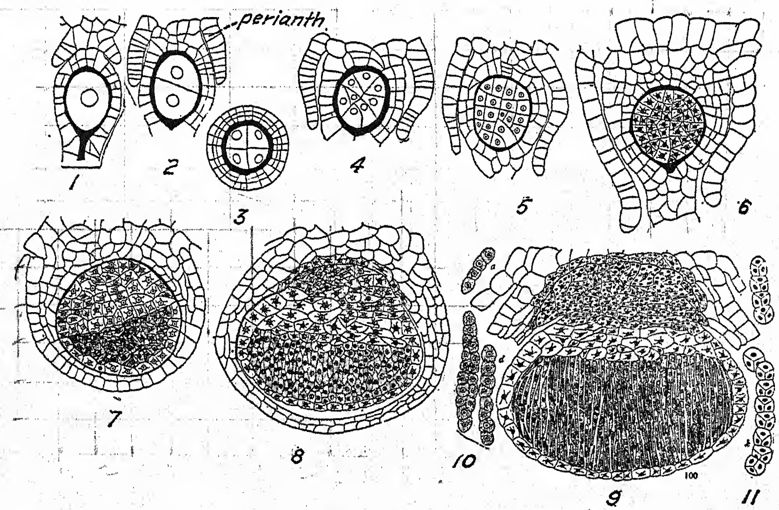


FIG. 250. Stages in the development of the sporophyte of *Marchantia.* *1*, venter of archegonium containing zygote; *2*, two-celled sporophyte; *3*, cross section of venter of archegonium and young sporophyte; *4*, *5*, *6*, further stages in growth of sporophyte; *7*, differentiation of spore-bearing tissue in sporophyte is evident; *8*, *9*, differentiation of foot, stalk and spore capsule is shown; *10*, chains of spore mother cells which develop by the division of the elongated cells shown in the capsule in *9*; *11*, each spore mother cell forms four spores arranged in a sphere. (From Durand in the Bulletin of the Torrey Botanical Club.)

the four others into the short stalk and the foot which penetrates the tissues of the archegonial branch of the gametophyte. The mature sporophyte consists of three parts, foot, stalk, and capsule. The stalk is very short, and the sporophyte therefore does not project much from the surrounding parental tissues. The capsule is a comparatively simple structure. Its wall consists of a single layer of cells. Enclosed by this are many large round spore mother cells; and certain long narrow pointed cells, with spirally thickened

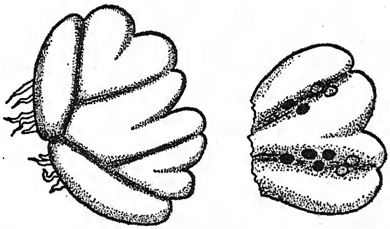


FIG. 251. Gametophytes of a liverwort, *Riccia*. The bodies embedded in the right-hand plant are sporophytes.

walls, called *elaters*. Each spore mother cell undergoes the reductional divisions and forms a spore tetrad.

As the sporophyte of *Marchantia* develops, the venter of the archegonium around it also grows, and so continues to enclose it. Furthermore, the ring of cells at the base of the venter now develops into a cylindrical sheath, the *perianth*, enclosing both the archegonium and its enclosed sporophyte. The latter, therefore, is completely invested by tissues of its parent, the gametophyte.

When mature, the stalk of the sporophyte elongates slightly, pushing the capsule through the calyptra and perianth. At the same time the capsule wall splits into several teeth, freeing the mass of spores and elaters inside. The elaters coil and uncoil with changes in moisture content, and being mixed with the spores knock these about and scatter them in all directions.

184. Reproduction by Spores.—Such spores as chance to encounter water and a favorable temperature germinate, developing a long tube which extends out through the spore wall. This tube divides and cell division continues, until a plate of cells is formed. This plate of cells differentiates into the haploid green thallus, the gametophyte; its cells becoming photosynthetic tissue, storage tissue, rhizoids, and so forth, according to their relative positions.

Some other liverworts are simpler than *Marchantia*, having the antheridia and archegonia on the main thallus instead of on special branches. Some have a body that is bordered by a simple sort of

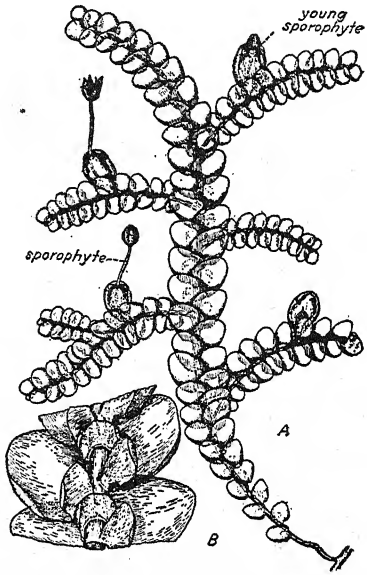


FIG. 252. A leafy liverwort, *Porella*. *A*, branch of the gametophyte bearing sporophytes; *B*, under surface of a portion of a branch showing theminute scale-like leaves. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

leaves of small size. The life cycle of all, however, and the reproductive structures, are very similar to those of *Marchantia*.

SUMMARY

185. Mosses and Liverworts.—The mosses and the liverworts are certainly related; they possess reproductive structures (antheridia and archegonia) which are almost identical; their sporophytes are quite similar; they differ chiefly in the external appearance of their gametophytes. Both sporophyte and gametophyte generations in mosses and liverworts are relatively simple organisms, not possessing true roots, stems, or leaves (although the moss gametophyte has a very simple type of these organs). Hence it might be possible to place these plants in the Thallophytes. But in the possession of antheridia and archegonia they resemble the Pterido-

phytes,[7] and none of the plants so far included in the Thallophytes has reproductive bodies which resemble these. The antheridium or oögonium of a Thallophyte (for example *Fucus*) is a sac composed of a cell wall only, all of its contents being used in the formation of the gametes; the antheridium of the Bryophytes and Pteridophytes is a sac composed of a jacket of several cells which encloses the gametes, and the archegonium also has a many-celled outer layer. Because of their possession of many-celled gamete-containing organs (particularly the archegonia with their characteristic venters and necks) the mosses and liverworts are separated from the Thallophytes and placed in a group by themselves, the Bryophytes.

[7] Both Bryophytes and Pteridophytes, with certain seed plants, have been sometimes grouped together under the term Archegoniates.

CHAPTER XXI

Club Mosses

The plants usually called club mosses are not common in all lands as are the true mosses. Most kinds are tropical; the remainder are found for the most part in regions where grow evergreen forests—pine, hemlock, and so forth—and especially on mountains. There are two main groups of club mosses, commonly distinguished by the names "Great Club Mosses" and "Little Club Mosses." The first with their dark green often needle-shaped leaves resemble miniature pine trees more than they do mosses. The second kind

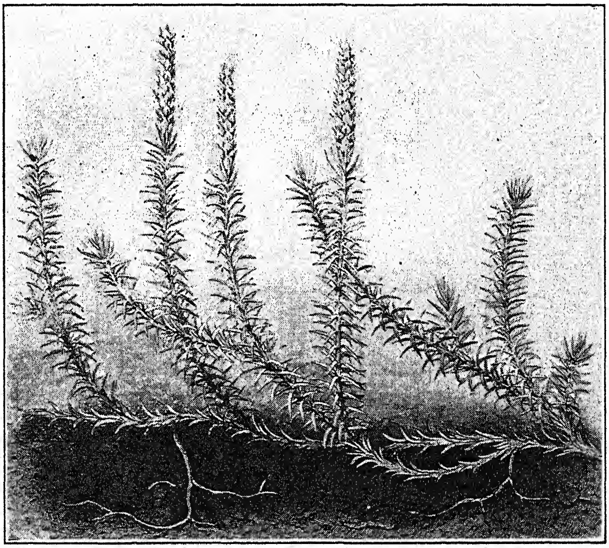


Fig. 253. A club moss, *Lycopodium annotinum*. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

is composed of plants which look like rather large mosses, with fairly broad or scale-like leaves. The leaves are closely grouped at the ends of the branches, giving the latter a club-like thickened appearance, whence the common name. Botanically speaking, the

great club mosses are species of *Lycopodium*, the little club mosses are *Selaginella*. Both kinds include many creeping, trailing, or climbing kinds; some species of each are upright, seldom growing, however, more than a foot or two in height. Some of the creeping kinds of *Lycopodium* are so pine-like that they have received the name of "ground-pine." These are often gathered and used for Christmas decorations, both in the fresh state and, dried and artificially colored, in the Christmas wreaths common in shops. Some sorts of *Selaginella* are grown in greenhouses for decorative purposes. A well-known species of *Selaginella* will be described here as an example of the group.

186. The Sporophyte.—A close examination of the plant discloses that the leaves and stems are complex in structure and

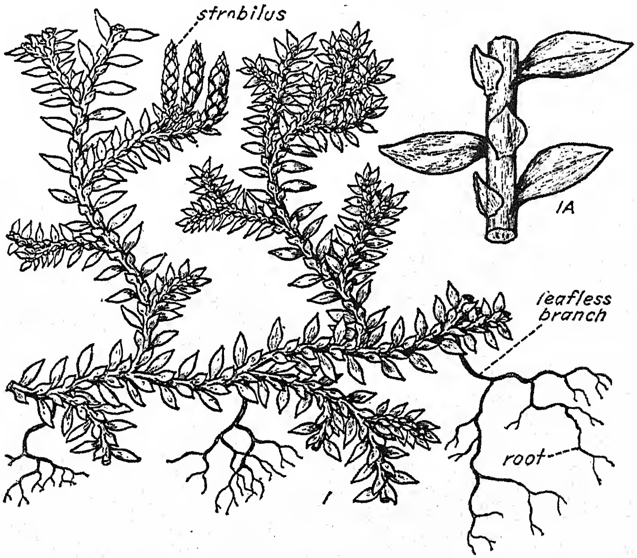


FIG. 254. A common cultivated *Selaginella*. *1*, habit of sporophyte; *1A*, portion of stem showing leaf arrangement. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

comparable to those of seed plants and ferns, not simple as in the mosses. Furthermore, true roots are present, borne on certain branches of the stem which hang down and touch the soil. The plant body thus differs markedly from that of an ordinary moss. When we study its reproduction we find that it bears spores, not

gametes; and in this also it is very different from *Mnium* or *Polytrichum*, the leafy plants of which are gametophytes, the spores being produced by a thallus plant parasitic upon this gametophyte. It is evident, then, that *Selaginella* resembles, both in structure and in reproduction, a fern much more than it does a moss; for its stem and leaves are parts of a sporophyte as in the fern, and resemble those of the fern in complexity; and roots are present as in the fern. Since these characters, rather than superficial appearance, are used as the basis of classification, we class the club mosses as Pteridophytes and not as Bryophytes—in spite of the common name, which would imply that they belong to the same group as the true mosses.

The stem is long, branching, and, in the kind here considered, creeping. The leaves are of two sizes, but all small, and borne in four rows on the stem: two outer rows of the larger size, two within these of very small scale-like leaves. No sporangia or spores are to be found on most of the leaves—they are purely vegetative. But on certain short side branches the leaves are closely crowded together, and bear sporangia. *Selaginella* then resembles those few ferns which have a differentiation between sporophylls and vegetative leaves; but the specialization of structure is carried a step further, in that the sporophylls are massed together on a short stem to form a compact cluster. Such a cluster of sporophylls is called a *cone*, or, more technically, a *strobilus* (plural, *strobili*). In some species of *Selaginella* the strobili are on the ends of the main branches instead of forming side branches.

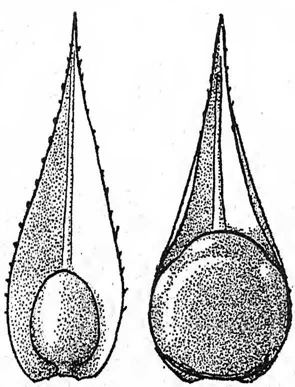


FIG. 255. Sporophylls and sporangia of *Selaginella*. Left, microsporophyll and microsporangium; right, megasporophyll and megasporangium; the four large spores in the megasporangium are visible through its wall.

187. Reproduction by Spores.—Each sporophyll of a strobilus bears usually one sporangium, on its upper surface very near its attachment to the stem. Near the base of the sporangium is a small tongue of cells, the *ligule*, which, though of no known benefit, is very characteristic of this group of plants. The sporangium is a fairly simple globular structure whose wall is composed of a few

layers of cells, and is attached to the leaf by a short stalk. There is no annulus, no mouth or special opening.

Certain sporangia, usually, it seems, those nearest the ground, are, when mature, conspicuously four-lobed. This is due to the presence inside each of four relatively large, heavy-walled spores, which are formed by reductional division from a single spore mother cell. Other sporangia, however, are smooth in outline, more or less ovoid; and, when broken, prove to contain a very large number of very small spores. This sort of plant, therefore, produces *two kinds of spores*. Since they differ in size they may be distinguished by the terms *megaspore* and *microspore* (see Fig. 152); just as the two sizes of gametes are distinguished. It must be borne in mind, however, that these are not gametes, and in no way correspond to the mega- and microgametes of a fern or moss. They develop into mature plants without union.

Since the two sorts of spores are found in separate sporangia, the latter receive the same prefixes as the spores they produce,

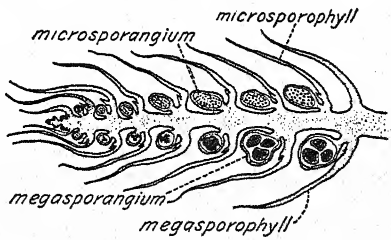


FIG. 256. A longitudinal section of a strobilus of *Selaginella*. This strobilus developed in a horizontal position.

and are called *megasporangia* and *microsporangia*. Similarly the leaves that bear the sporangia are *megaspororophylls* and *microsporophylls*. Both kinds of sporophylls are usually found in one cone.

The spores grow into gametophytes, just as do the spores of ferns and mosses. There are two kinds of spores and there are two kinds of gametophytes: one kind—that which develops from the megaspore—is comparatively large, and produces only megagametes; the other is very small, and forms only microgametes. In ferns both sorts of gametes are formed (though perhaps at different times) by the same gametophyte. This is also true of

many mosses. In some kinds of mosses,[1] and also in certain kinds of liverworts, the two kinds of gametes are formed by different individuals. Even, here, however, the two individuals that give rise to different gametes look, in the main, alike; and the spores from which they come look alike. In *Selaginella*, not only are mega- and microgametes formed by separate gametophytes, but these plants differ in size and structure, and so also do the spores from which they develop. The differentiation between gametes is, as it were, visibly anticipated in the plants which form those gametes and in the spores which form those plants. It is convenient, also, when we come to apply distinguishing terms, that it is the small spore, or microspore, that develops into a small gametophyte, which may therefore be termed a *microgametophyte*, which in turn produces the small sort of gametes—microgametes. Similarly the megaspore grows into a *megagametophyte*, which forms only megagametes.

The spores of ferns and of many kinds of mosses are both structurally and functionally alike. The spores of other mosses and certain liverworts are structurally alike but must possess some invisible functional difference, since they develop into plants which produce different sorts of gametes. The spores of *Selaginella* are both structurally and functionally different. The last condition is known as *heterospory;* all others are *homospory*. *Selaginella* is said to be heterosporous, all true ferns, mosses and liverworts homosporous. *Lycopodium* also is homosporous.

188. Development of the Gametophytes.—The history and structure of the gametophytes of *Selaginella* is as follows. The megaspore is discharged, and, if it encounters certain conditions of moisture and temperature, begins to grow, without escaping from the megaspore wall. Cell division occurs, and differentiation, so that we have a many-celled differentiated plant developed; but this plant still occupies no more than the space within the wall of the original spore. The megaspore contains a large quantity of stored food, on which the new plant, the gametophyte, lives; it may therefore be considered a parasite upon its parent the sporophyte, though detached from it. When mature it consists of

[1] Many mosses bear both kinds of gametes, but on different branches, and at different times. Some kinds of mosses have both antheridia and archegonia together on one stem-tip. A few kinds of the mosses that have been studied seem to bear only one sort of gamete on one plant.

some large cells, still containing much stored food; and a mass of small cells, some of which are differentiated to form archegonia. The latter resemble those of a fern, the venter being embedded

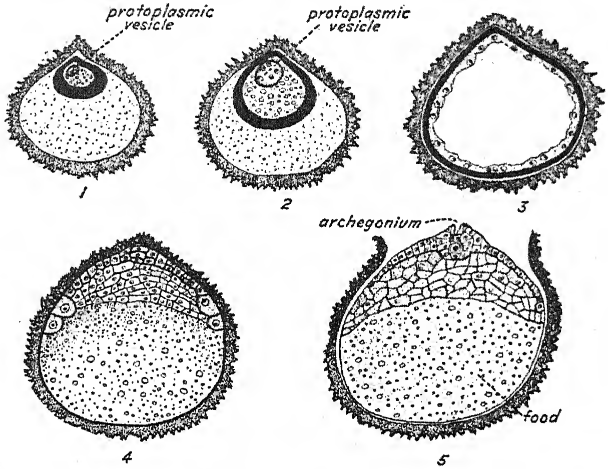


FIG. 257. The development of the megagametophyte of *Selaginella* as shown by median sections; semi-diagrammatic. *1*, megaspore, one nucleus in protoplasmic vesicle; *2*, nucleus of megaspore has divided to form several nuclei in protoplasmic vesicle; *3*, protoplasmic vesicle and inner membrane have expanded; *4*, nuclei arranged at one end of spore and separated by cell walls, forming an immature megagametophyte; *5*, archegonium organized, spore wall splits open. (Redrawn from Lyon, in the Botanical Gazette.)

in the thallus and the short neck very slightly projecting. When these cells have been formed, a small amount of growth in size does take place—sufficient to crack the megaspore wall, through which the mass of small cells containing several archegonia slightly protrudes. A small amount of chlorophyll may develop, and the little plant may manufacture a small part of the food which it needs. This is now the mature megagametophyte, corresponding to the heart-shaped thallus of a fern, except that it has produced only megagametes.

The microspore develops similarly. Cell division and differentiation occur within the microspore wall. The result is a layer of cells surrounding a central mass of cells; each of the latter becomes a microgamete, in general structure like a fern microgamete

(but, strangely enough, more like a moss microgamete, for it has only two flagella). This is all there is of the microgametophyte. It is practically nothing but a single antheridium; yet it is an

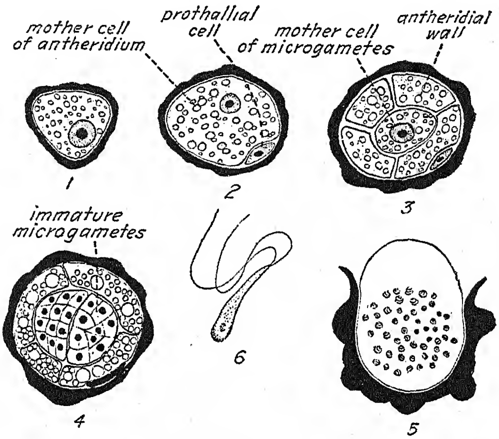


FIG. 258. The development of the microgametophyte of *Selaginella* as shown by median sections; semi-diagrammatic. *1*, microspore; *2*, prothallial cell and mother cell of antheridium; *3*, wall of antheridium and mother cell of microgametes; *4*, mother cell of microgametes has divided; *5*, antheridium wall has disintegrated, microspore wall cracked open, microgametes differentiated; *6*, a single microgamete. (From Lyon, in the Botanical Gazette. *4* and *5* redrawn.)

individual plant and corresponds to the whole heart-shaped thallus of a fern, if the latter bore only microgametes. It is entirely parasitic, and lives its short life entirely upon food derived from the sporophyte. The microgametes are finally liberated by the disintegration of most of the cells which surround them (which is equivalent to the death of the whole little plant), and if, as is likely, they find themselves in a film of water in the soil, swim about in it. The rest of the story—the union of gametes—takes place almost exactly as in a fern or moss; the zygote is formed within the venter of the archegonium.

These gametophytes are so small and inconspicuous that they are easily forgotten. It is easy to omit them altogether, and think of megaspore and microspore producing directly, or becoming, megagamete and microgamete. The next step is to say that megaspore and microspore unite and form the zygote; which, of course, is absurd. It is necessary, therefore, to emphasize the fact

that these gametophytes are truly individual plants, growing, respiring, reproducing like other plants; just as much *Selaginella* plants as is the leafy sporophyte; just as much gametophytes as is the thallus of a fern or the leafy plant of a moss.

189. Gametic Reproduction and Development of Sporophyte.—The zygote immediately develops, within the venter, into an embryo. The details are slightly different from those of the growth

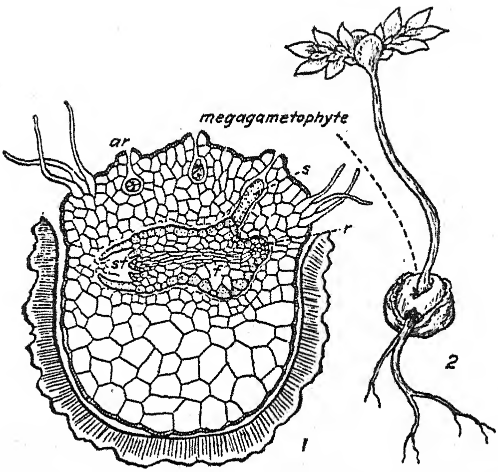


FIG. 259. *1*, section of a mature megagametophyte of *Selaginella* which has ruptured the megaspore wall and exposed the archegonia (*ar*); one of these contains a young sporophyte, with root (*r*), stem (*st*), foot (*f*) and suspensor (*s*); *2*, a megagametophyte and a sporophyte which has developed root, stem and leaves. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

of a fern embryo. Of the two cells formed by the first division of the zygote, one elongates and divides, forming a thread called a *suspensor*, which pushes the other cell ahead of it down into the large storage cell of the megagametophyte. This storage cell now divides into many cells, from which the developing embryo absorbs food. The embryo is therefore a parasite when young, just as is that of a fern; but the *Selaginella* embryo is parasitic upon a gametophyte that is itself almost entirely a parasite upon *its* parent. The cell at the end of the suspensor grows into the embryo proper—forming a foot, by which the young plant continues to absorb food from its parent; a primary root, which grows out of the gametophyte

and into the soil; a primary stem, which grows up into the air; and, on the end of the stem, a pair of primary leaves which manufacture food. The primary stem continues its growth, forming

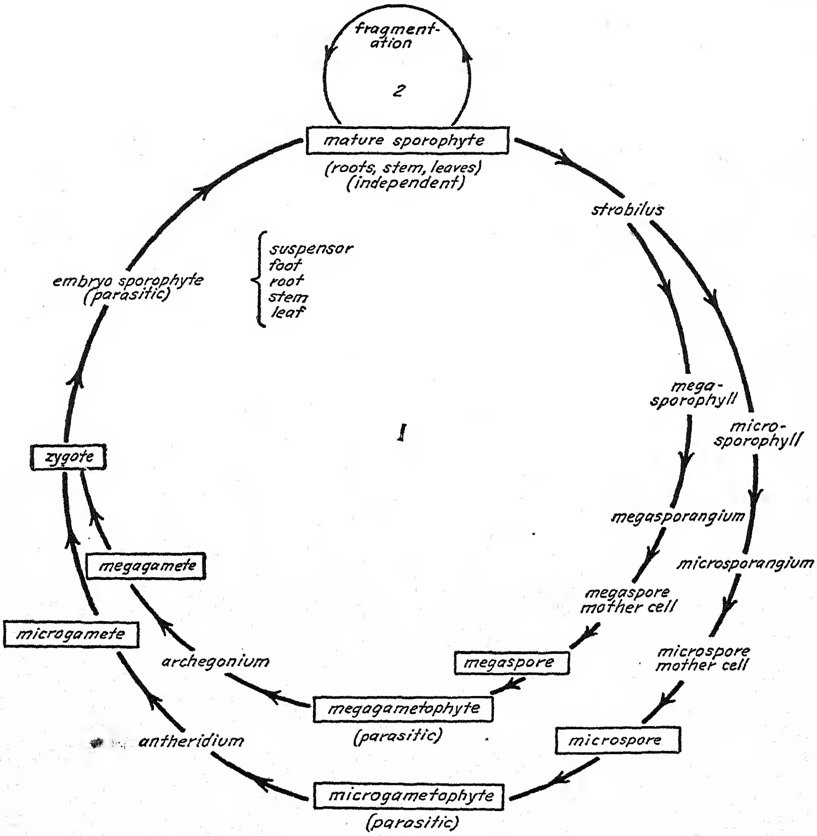


FIG. 260. Diagram of the life-cycle of *Selaginella.*

more leaves, branches, roots, and finally strobili. The megagametophyte, *still enclosed by the wall of the megaspore*, may be observed for some time attached (by the foot of the embryo) to the young sporophyte at the junction of primary stem and primary root.

190. Comparison with Other Groups of Plants.—Although the general scheme of the life cycle of *Selaginella* is very similar to that of a fern, many of the details are different; *and in these details*

Selaginella resembles a seed plant. These points may be briefly summarized as follows:

1. The sporophylls of *Selaginella* are grouped to form a compact specialized body, the cone or strobilus. This corresponds to the cone of a pine or to the flower of a geranium.

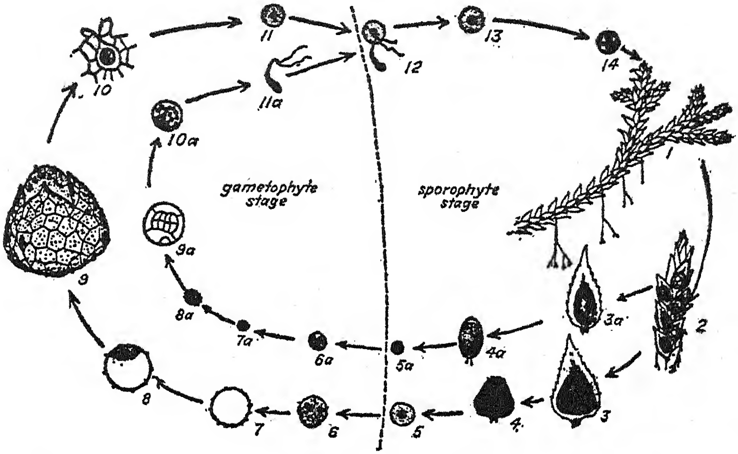


FIG. 261. Diagram of the life-cycle of *Selaginella*. (After Schaffner from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

2. Two visibly differentiated kinds of spores are produced, each forming a gametophyte which produces only one sort of gametes.

3. The gametophytes are very small and almost entirely dependent upon the sporophyte for nutrition.

4. A suspensor is developed in the growth of the young sporophyte which pushes the latter into the midst of the food stored in its parent, the megagametophyte.

To which we may add that, in at least one species of *Selaginella*, the microspores enter and germinate in the megasporangium; the megagametophyte is formed in the same place; and the union of gametes and the development of the embryo take place in this sporangium. All this very closely resembles what happens in seed formation.

If we disregard these differences of detail, we see that *Selaginella* has many important features in common with the ferns. It forms archegonia and antheridia, has alternation of generations, and the sporophyte is a complex leafy plant. For these reasons we class

Selaginella (and *Lycopodium*) among the Pteridophytes (though not among the ferns). The same is true of a number of other plants. Some of the most interesting of the latter are the so-called "horsetails" or "scouring rushes," botanically species of *Equisetum*. These are curious plants with very small scale-like leaves (photosynthesis occurs chiefly in the stems). One common name is derived from the fact that the cell walls of the stem are heavily

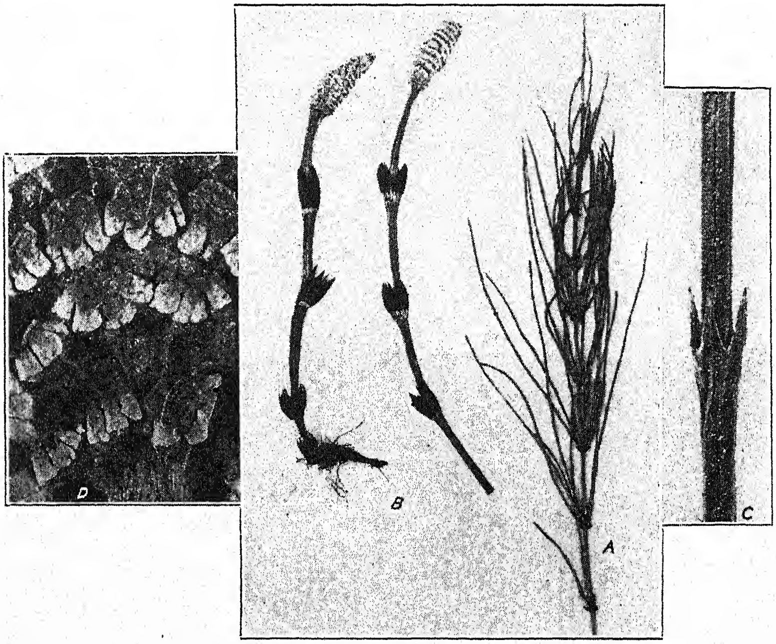


FIG. 262. One of the horse-tails, *Equisetum arvense*. *A*, a vegetative shoot; *B*, spore-bearing shoots, with a portion of the rhizome and a few roots; each shoot is terminated by a strobilus; *C*, a portion of a branch of the vegetative shoot much enlarged, showing the small scale-like leaves; *D*, a portion of the strobilus much enlarged; the small white sacs are sporangia borne on scale-like sporophylls; the powdery dark masses beneath these are composed of spores.

impregnated with silica, and the plants have therefore been used in the kitchen for scouring. They grow commonly along streams, and, strangely enough, often on railroad tracks and embankments. They form spores in strobili (they are homosporous), and the spores develop into small thalli, the gametophytes. Evidence derived

from fossils indicates that in times long past these plants and certain relatives of them which are now extinct were conspicuous features of the landscape. Some of the extinct kinds apparently attained large size.

All these plants—club mosses, horsetails and others—which resemble ferns in certain details, are often spoken of as the "Fern Allies."

CHAPTER XXII

THE PINE

191. Great Groups of Plants.—According to the system of classification used in this book, all known plants are included in four great groups. Of these, three have been already discussed, namely, Thallophytes, Bryophytes, and Pteridophytes. The remaining group is composed of the Spermatophytes or seed plants.

The chief differences between these great groups of plants may be represented in a table. Other differences can be added.

	True Roots, Stems, Leaves	*Archegonia*	*Vascular Bundles*	*Seeds*
Thallophytes	No	No	No	No
Bryophytes	No	Yes	No	No
Pteridophytes	Yes	Yes	Yes	No
Spermatophytes	Yes	Some	Yes	Yes

The Spermatophytes are the most common and familiar of all our plants and the ones upon which human life and civilization are principally dependent. The group is itself composed of two divisions, named Gymnosperms and Angiosperms. Loosely speaking, Gymnosperms are cone-bearing seed plants (such as pines); and Angiosperms are flower-bearing plants (such as lilies, grasses, and peas). The word gymnosperm literally means "naked seed"; angiosperm means "enclosed seed." The true nature of this distinction will become plain later.

Our first problem is to understand what a seed is; for the seed has contributed largely to the success and commonness of the Spermatophytes; and, furthermore, is the chief common characteristic which enables us to group them together. A seed is a complex body, far more complex than a spore or a gamete or any of the other reproductive bodies we have studied. It cannot be explained in a few words or defined in a sentence. It contains an entire embryo plant, usually surrounded by a tissue containing stored food, and by a specialized seed coat. In order to understand the origins and significance of these structures, it is necessary to study the life history of a seed plant. The Gymnosperms will be first discussed, and the pine will be the principal example used.

192. Gymnosperms.—There are about 500 species of Gymnosperms as compared to more than 130,000 species of Angiosperms. The Gymnosperms are woody, perennial plants, and with few exceptions are evergreen. As sources of lumber and of turpentine and resin they are of great economic importance. Some of them (*Zamia*, *Dioon* and other Cycads) have fern-like foliage and are palm-like in their general appearance, one (*Ginkgo*) bears fan-shaped broad leaves, but most of the Gymnosperms have needle-like leaves. Among the latter may be mentioned the spruces (*Picea*), firs (*Abies*), larches (*Larix*), cypress (*Taxodium*), junipers—frequently called cedars (*Juniperus*), —hemlocks (*Tsuga*), red-woods (*Sequoia*), and the pines (*Pinus*).

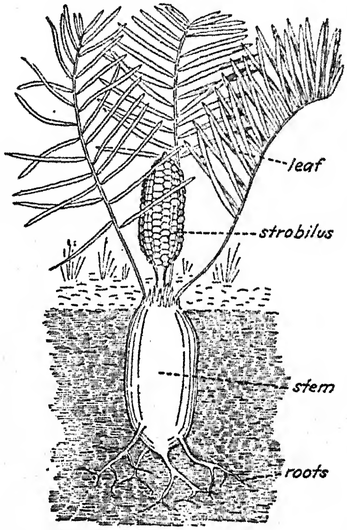


FIG. 263. A cycad. Mature sporophyte of *Zamia* bearing a carpellate strobilus. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

193. The Pine—General Morphology.—The pine tree is a complex leafy plant similar in the main to the leafy plants (sunflower, geranium, etc.) used as examples in our study of the plant as a whole. It possesses an upright woody stem, composed of a stele, with xylem, phloem, vascular rays, pith, and cambium; a cortex; and an epidermis, later replaced by corky tissues developed in the cortex by a cork cambium. The roots also consist of epidermis, cortex, and stele, with tissues arranged in general similarly to those of the first root studied. The leaves are of a somewhat unusual type. They are the familiar "pine needles," long, narrow, hard, and green. They are borne in clusters of two, three, or five (according to the sort of pine) on very short branches arising from the ordinary branches of the stem. These branches are known as "spur shoots"; they are so small as to be scarcely visible. Surrounding the base of each cluster of needles there is a thin sheath, which corresponds to the bud scales of ordinary branches. The spur shoots themselves arise in the axils of scale-like leaves which cover

the ordinary branches, and which give the latter their characteristic rough appearance. The leaves themselves, when studied in cross section, show an epidermis (heavily cutinized) with stomata deeply

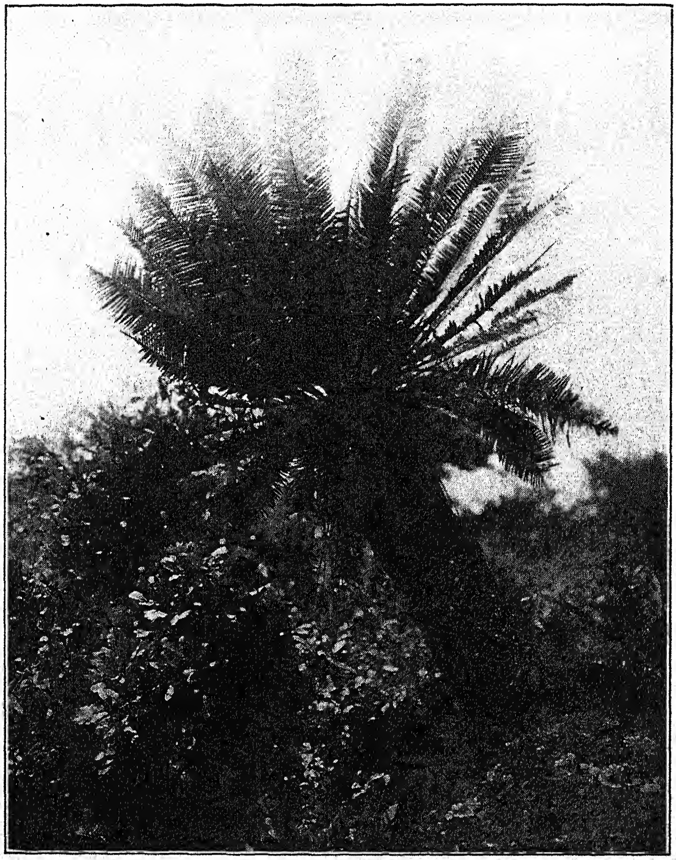


FIG. 264. A cycad, *Dioon edule*. (Courtesy of C. J. Chamberlain and the Botanical Gazette.)

sunk in pits; mesophyll, rather compact and containing few air spaces; and a central vein containing a couple of fibrovascular bundles. Their small surface, sunken stomata, cutinized epidermis, and compact mesophyll enable the leaves to withstand very dry conditions without excessive loss of water. This is one of the characteristics which make it possible for the plant to live through

the winter without shedding its leaves, whence it derives its popular name of an "evergreen."

194. **The Pine—Reproduction.**—As in a club moss, reproductive organs are limited to certain branches. Each of these is composed of a short central axis and a number of close-packed scale-like leaves; and on these leaves are found sporangia containing spores. The pine tree is, therefore, a sporophyte; and, just as in *Selaginella*,

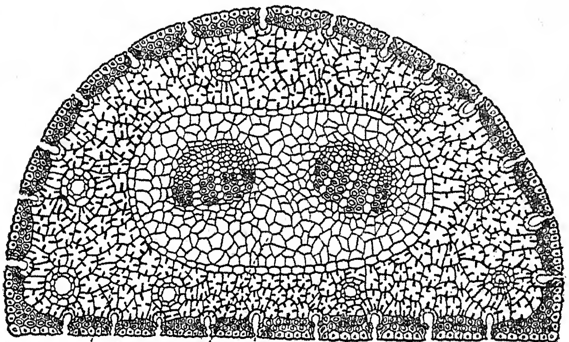


FIG. 265. Cross section of a pine leaf.

the spores are borne only on certain leaves—the sporophylls—which are grouped on a short stem to form a cone or strobilus. If a number of pine trees is examined, it becomes evident that two sorts of cones are formed on the same or different trees. One sort is fairly long (in most kinds of pines) and cylindrical, and several are produced in a cluster at the base of the season's vegetative shoot. The other sort is (usually) shorter, more oval, and produced singly at the tip of the new growth (though afterwards it bends over and the new shoot grows straight past it). The scales (sporophylls) of the two kinds of strobili also differ. They are distinguished by different terms. Those of the first kind of strobilus are called *stamens*, and the whole strobilus a *staminate* strobilus; those of the other, the smaller, rounder strobilus, are called *carpels*, and the whole strobilus a *carpellate* strobilus.

A study of the contents of the sporangia of these sporophylls reveals that the stamen bears a large number of rather small spores; the carpel a smaller number of somewhat larger spores. These spores are distinguished (just as are gametes) by the prefixes

micro- and mega-. Furthermore since a stamen bears only microspores, we call it a *microsporophyll*, and its sporangia *microsporangia*. Similarly the carpel is a *megasporophyll* and its sporangia *mega-*

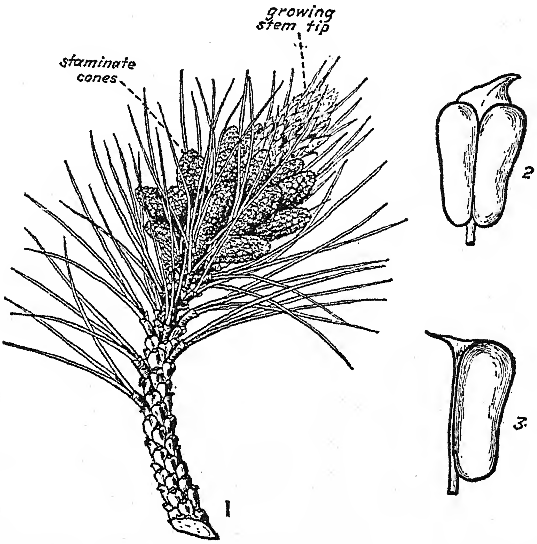


FIG. 266. Staminate cones (strobili) of the pine. *1*, branch with cluster of cones at the base of the new growth; *2*, a single microsporophyll and its sporangia seen from below; the two sporangia are evident; *3*, a single microsporophyll and its sporangia seen from the side. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

sporangia.[1] It is worth noting that the microsporophyll is not necessarily a "small sporophyll," for it is often larger than a megasporophyll of like age. These organs are named for the size of spore they produce, not for their own size.

All these characteristics are similar to those of *Selaginella*. Here also two sorts of spores are produced, in sporangia, which are on sporophylls, which are grouped into strobili. The pine differs from *Selaginella* in that the sporophylls do not resemble the vegetative leaves; and the two kinds of sporophylls do not resemble each other very closely; furthermore, only one kind of spore is formed in one strobilus.

[1] The words stamen and carpel were applied before the true nature of these organs was understood. Micro- and megasporophylls are better terms, since they explain themselves exactly by their derivation.

195. Microsporophylls — Microspores — Microgametophytes.— The stamen is a nearly triangular scale, bearing on its under surface two swellings; these are the sporangia. If we study a prepared section of a microsporangium, we find that it consists of three

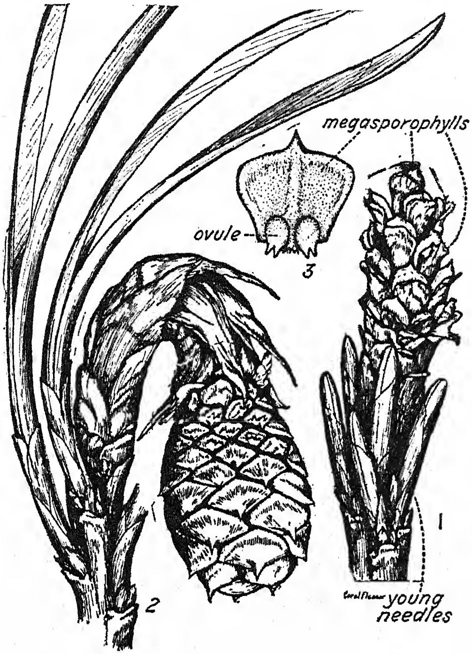


FIG. 267. Carpellate cones of the pine. *1*, young carpellate cone; megasporophylls are spread apart; *2*, older carpellate cone; pollination has occurred, the sporophylls have closed together and the cone has bent with its tip downward; *3*, a single megasporophyll and its two ovules, from a young cone.

tissues: a wall; a single layer of large square cells, the *tapetum*, lining the wall; and a number of large rounded cells in the interior. These latter are spore mother cells; each divides, just as in a fern, into four spores; and in these divisions reduction of chromosome number occurs. The tapetum cells are used as food during the formation and growth of the spores, and are therefore not found in a mature microsporangium.

The spores are haploid just as in the fern; and, just as in the fern, each develops into a gametophyte. Here appears one of the characteristic peculiarities of seed plants: the microspores germinate

and begin to develop into gametophytes *while still within the microsporangium*, instead of after they have been discharged, as in a fern or moss. This early growth is of the peculiar type already encountered in *Selaginella*, which involves no increase in size; cell division takes place, and differentiation; but the resulting structure is entirely surrounded by the wall of the spore from which it developed. By successive cell divisions, four cells are formed. Of these, two are very small cells (*prothallial cells*) which die and disintegrate almost as soon as formed. One of the remaining ones

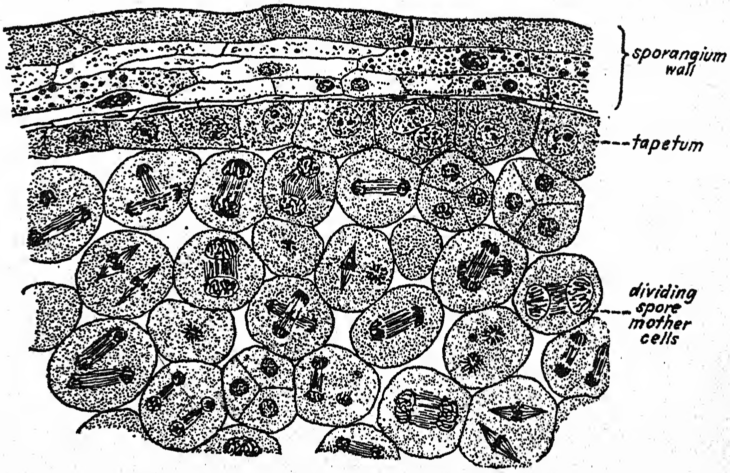


FIG. 268. Portion of a section through a microsporangium of the pine. The spore mother cells are dividing. ×500. (From Coulter and Chamberlain, *Morphology of the Gymnosperms*, University of Chicago Press.)

is a large cell, occupying most of the space within the spore wall; it is called the *tube cell* (the reason will appear later). The other cell is a small cell which lies near the two degenerating cells and projects into the tube cell; it is known as the *generative cell*. Meanwhile, two so-called *wings* are formed on the cell wall. They are projecting hollow structures, composed of dead material and filled with air (they are therefore not cells). At the time the microspore has germinated thus far, the microsporangium breaks by a longitudinal slit, the young gametophytes are released and, because of the buoyancy due to their wings, float out upon the air. They may be carried large distances by the wind, and settle to the ground only slowly. The young gametophyte that has developed from a

microspore, in the stage of development that it has reached at the time of discharge, is called a *pollen grain*. An account of its further development and its formation of gametes must be postponed until we have studied the carpel and the megaspores. We will leave the pollen, for the present, floating in the air. One fact, however, may be mentioned at this time: this gametophyte, which

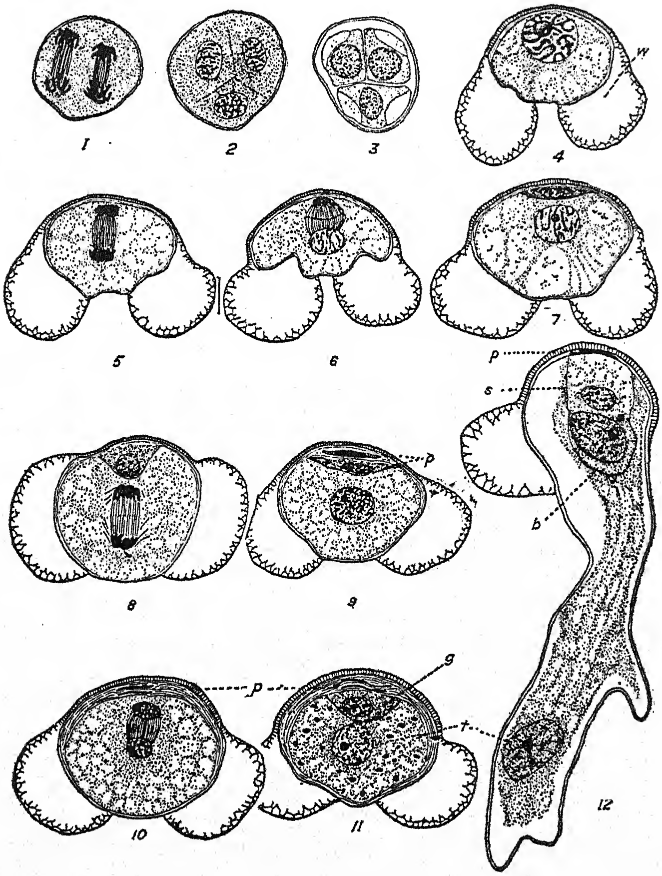


FIG. 269. Stages in the development of microspore and microgametophyte of the pine. *1*, pollen mother cell dividing; *2*, *3*, microspores forming; *4*, a single microspore; *5*, *6*, *7*, *8*, *9*, *10*, *11*, development of pollen grain; *12*, a germinating pollen grain. *t*, tube cell; *g*, generative cell; *p*, prothallial cell; *w*, wing; *s*, stalk cell; *b*, body cell. ×575. (From Coulter and Chamberlain, *Morphology of the Gymnosperms*, University of Chicago Press.)

has developed from a microspore, will, when mature, form only microgametes; and is therefore called a *microgametophyte*. The size and kind of gamete that is formed are therefore, as it were, anticipated in the size and kind of gametophyte which forms it, and in the spore from which that gametophyte developed.

196. Megasporophylls — Megaspores — Megagametophytes. — Turning now to the carpels or megasporophylls, we find them also scale-like, shorter and broader than the microsporophylls, triangular in shape. Beneath each sporophyll is another scale, of different appearance, known as a *bract*. On the upper side of the sporophyll are two small white swellings, which we might naturally assume to be the megasporangia. A study of a section of one of these bodies, however, discloses the fact that it is more than a sporangium. It is composed of two parts: an inner globular mass of cells, which forms the megaspores, and is therefore the megasporangium; and an outer tissue, which grows up as a ring or circular sheath of cells from the base of the sporangium, and finally encloses the latter completely except for a small hole leading to the top of the sporangium. This sheathing tissue is called the *integument;* the small hole in it is the *micropyle*. The megasporangium within is often called the *nucellus*. The entire body, composed of integument and megasporangium, is known as an *ovule*. This structure is peculiar to the seed plants; and is of great importance, for it develops into the seed.

Within the megasporangium a single spore mother cell is formed. This, as usual, divides to form four spores, and the first of these divisions is a reductional division. Of these four spores, only one usually develops. This megaspore not only commences growth while still within the sporangium, but completes it in that place. Neither the megaspore nor the resulting gametophyte is ever discharged from the megasporangium. Its growth is, therefore, parasitic. The mature gametophyte is a small ovoid thallus which has consumed in its growth most of the surrounding sporangium and reduced it to a thin membrane. At the end near the micropyle (though still separated from the latter by the remains of the megasporangium) several archegonia (usually four) are formed. They are essentially like the archegonia of Pteridophytes, each consisting of a neck and a venter containing a single megagamete; the differences being that both venter and neck are completely embedded in the thallus; and the venter and the enclosed megagamete are of

very large size for such structures. No microgametes are formed by this little plant. We call the latter, therefore, the *megagametophyte;* just as in the microgametophyte the size of spore and gametophyte is correlated with the size of gamete which the latter forms.

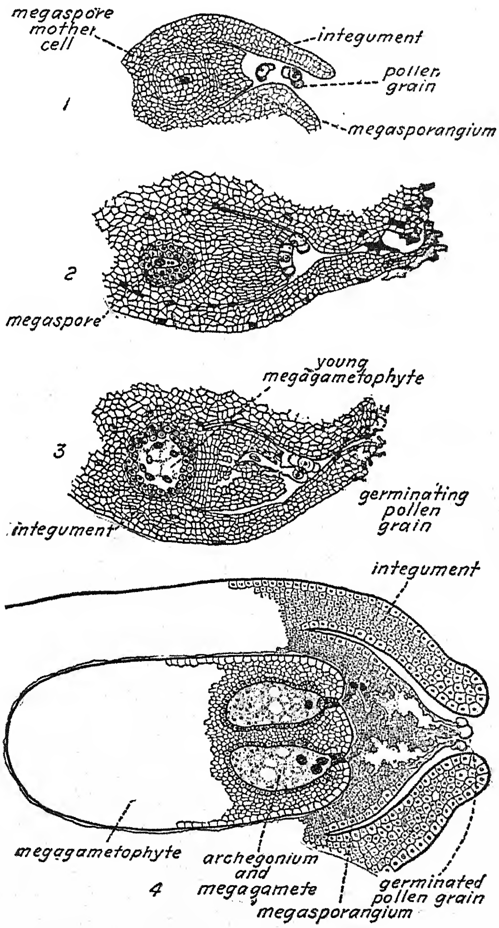


FIG. 270. Development of the megagametophyte of the pine. Vertical longitudinal sections through the ovule. *1*, megaspore mother cell in megasporangium; *2*, megaspore mother cell has divided into chain of four megaspores, one of which survives; *3*, megaspore germinating; *4*, mature megagametophyte showing two archegonia. The development of the microgametophyte also may be seen in the tip of the megasporangium. (*1, 2, 3* redrawn from Ferguson in the Proceedings of the Washington Academy of Science; *4* from Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

197. Heterospory.—The production of two visibly different sorts of spores each giving rise to a different sort of gametophyte is termed *heterospory*. It is not an exclusive feature of the Spermatophytes; for *Selaginella* and some other Pteridophytes are heterosporous. As has already been stated in connection with *Selaginella*, some plants produce different sorts of spores and gametophytes (as indicated by the kind of gamete formed) which are nevertheless termed *homosporous*, because the spores are not *visibly* different. For instance, certain liverworts form two sorts of gametophytes, one developing microgametes, the other megagametes; but all the spores of the plant look alike, even though there must be some internal, imperceptible difference. In other words, the spores of a homosporous plant are morphologically alike and physiologically either alike or different; those of a heterosporous plant are both morphologically and physiologically different. Heterospory is found in some Pteridophytes and in all Spermatophytes.

In the seed plants not only are gametes, gametophytes, and spores all of two kinds, but the sporangia and sporophylls (structures of the preceding generation) which produce the spores are also differentiated. It is these organs which correspond (if any do) to the sexual organs of animals, and they may therefore be called "male" and "female." But whereas the sexual organs of animals form, by reductional division, gametes directly, the male and female organs of plants form, by reductional division, spores which develop into small gametophytes which form gametes.

198. Pollination and Fertilization.—To resume the life history of the pine; we have followed the development of the megagametophyte to maturity (within the ovule), and that of the microgametophyte to the stage in which it is released into the air. The pollen grains are produced in immense numbers. When shaken, a tree which is producing pollen will emit large clouds of yellow dust, which are formed by countless numbers of minute microgametophytes. If there are carpellate strobili near, many of these pollen grains come to rest on their surfaces; and since, at this time, the megasporophylls are separated, the pollen grains sift down between them, and some of them come to lie on the surfaces of the ovules near the micropyles. Here they are caught by a sticky substance exuded from the micropyle; and by the drying and contraction of this substance are drawn down into the micropyle and finally lie at its lower end, in a little hollow called the *pollen chamber*

on the outside of the megasporangium. Here they resume growth, they germinate. The tube cell justifies its name by becoming a tube, which penetrates the megasporangium, branches, and absorbs

FIG. 271. Shedding of pollen from a young pine tree. Notice the cloud of pollen at the left, caused by shaking the tree. (From Gager, *General Botany*, P. Blakiston's Son & Co.)

food much as do the hyphae of a parasitic fungus penetrating its host. Some of the branches of this *pollen tube* pass entirely through the megasporangium and come in contact with the megagametophyte (Fig. 270); one usually penetrates an archegonium, passing between the neck cells. Meanwhile the generative cell of the microgametophyte divides, forming two cells (called *stalk* and *body* cells); one of these (the body cell) again divides, forming two microgametes. These become detached and float about within the tube cell. Each consists of little besides a nucleus. As the pollen tube grows, protoplasm streams down it into the newly formed part; and this protoplasmic streaming carries the microgametes with it.[2] Finally the tip of the pollen tube in the archegonium of the megagametophyte breaks, and its contents, including the two microgametes, are discharged into the archegonium. One of the microgametes, as usual, unites with the megagamete, and a zygote is formed.

[2] In some Gymnosperms, for instance *Cycas* and *Ginkgo*, the microgametes possess cilia which enable them to swim down the pollen tube.

Thus in a seed plant gametic union is preceded by the migration of one gametophyte in an immature state to a position near the other gametophyte; and by the formation of a special canal—the pollen tube—through which the microgametes pass directly to the

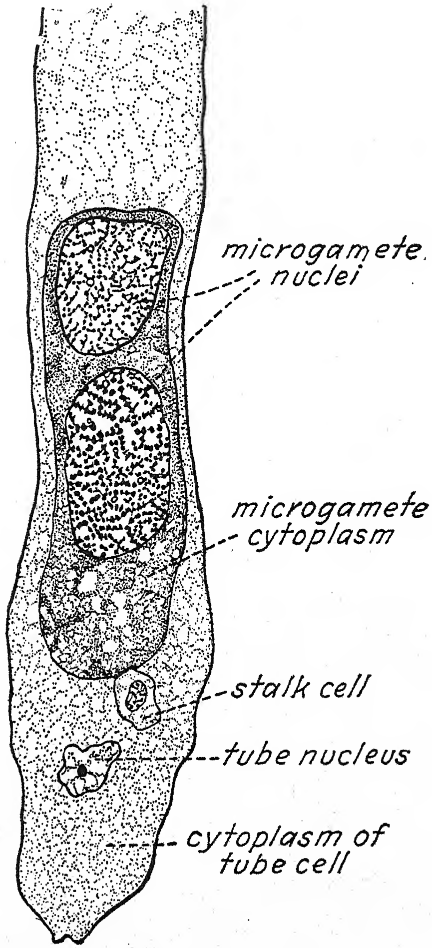


FIG. 272. Tip of pollen tube of the pine. (Redrawn from Ferguson.)

megagametes from their place of origin. The migration of the half-grown microgametophyte to the vicinity of the megagametophyte from the microsporangium is called *pollination*. In other

plants that we have studied, either both kinds of gametes were formed by one gametophyte, or, if only one kind was formed by one gametophyte, both sorts of gametophytes were near each other on the ground. In any case the microgamete could swim from its place of origin to the archegonium through water on the substrate. In the pine, both gametophytes are parasitic, and high in the air upon tissues of the sporophyte. No known microgametes can fly through the air; and pine trees are not likely to be submerged in rain-water or dew. Gametic union is made possible only by the transfer of the microgametophyte to the tissue upon which the megagametophyte is parasitic. It is worth noting that here, as elsewhere, the microgamete moves to the megagamete through a liquid. But, whereas in the Bryophytes and Pteridophytes that liquid is water, in the Spermatophytes it is the contents of a cell, the tube cell.

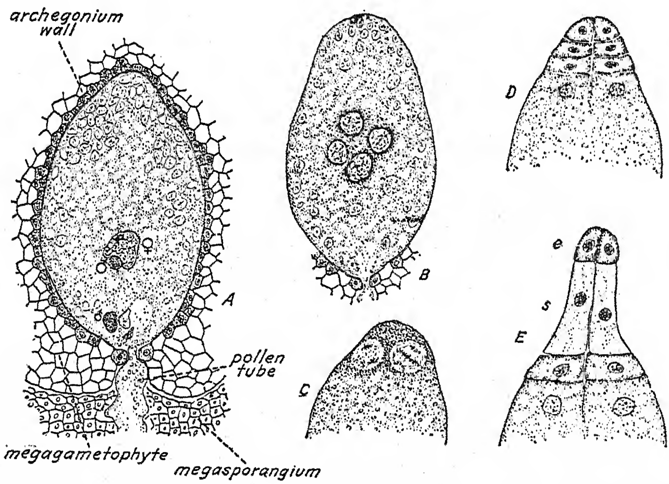


FIG. 273. Stages in the early development of a pine sporophyte. *A*, fertilization; *B*, zygote nucleus has divided into four nuclei which pass to the end of the sac farthest from the micropyle and divide again (*C*); *D*, walls have formed between the nuclei; *E*, suspensor cells (*s*) elongate, pushing proembryo cells (*e*) into the megagametophyte. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.; after Ferguson and Coulter and Chamberlain.)

It is a common error to confuse *pollination* with *gametic union*, and to speak of the pollen grain as the microgamete. The pollen grain, small as it is, is a four-celled, differentiated, *individual*

gametophyte—it is just as much a pine plant as is the tree. It develops from a spore just as does the green thallus of a fern or the leafy plant of a moss. No step in the life cycle has been omitted in a seed plant—but the gametophyte generation is so small and inconspicuous that it is easily overlooked.

199. Development of Zygote and Seed.—The zygote is formed by the union of gametes within the venter of the archegonium, just as in ferns and mosses. And the embryo which develops from the zygote is for a time a parasite upon its parent the gametophyte, again just as in ferns and mosses. The novel feature of the seed plant is that this gametophyte is itself still a parasite upon *its* parent, the original sporophyte—it is still enclosed within the ovule.

The history of the development of the zygote is as follows: It divides so as to form a small mass of cells at the end of a filament of cells. The latter elongates so as to push the former into the midst of the megagametophyte, which contains an abundance of

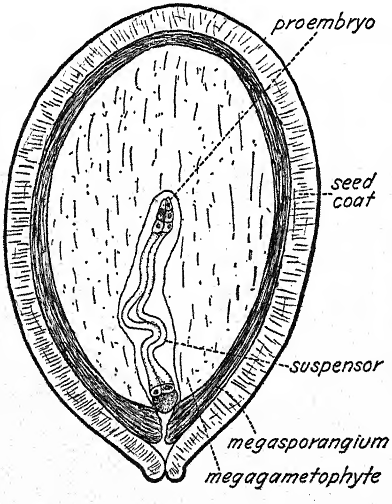


FIG. 274. Diagram of longitudinal section of an ovule containing a young pine embryo.

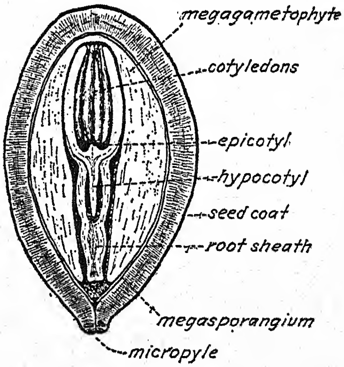


FIG. 275. Longitudinal section of a pine seed. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

stored food. This elongating filament is called the *suspensor*. The small mass of cells at the end of the suspensor grows, by further division, enlargement, and differentiation, into what is

usually known as the embryo proper. It becomes a long body composed mainly of a small stem. Very near the end of the stem away from the micropyle is a cluster of slender leaves, the *cotyledons.* These surround the stem tip, which is an embryonic region and, because it lies above the base of the cotyledons, is called the *epicotyl.* It is minute, somewhat cone-shaped, and is located in the center of the cluster of cotyledons. The rest of the stem, since it lies below the cotyledons, is called the *hypocotyl.* At its tip which lies near the micropyle of the ovule is an embryonic region. The hypocotyl is surrounded by a sheath. As the embryo enlarges towards the micropyle, it coils up the suspensor on the end of the sheath. When development has gone thus far, the embryo becomes dormant. Shortly thereafter the whole ovule, containing megagametophyte and embryo, falls from the tree; and this ovule with its contents is a seed.

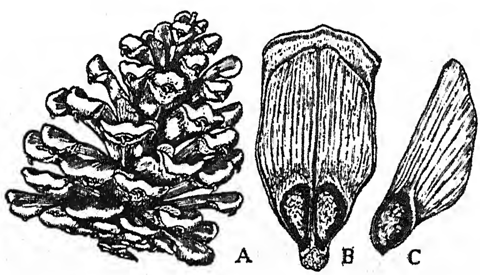


FIG. 276. *A*, mature carpellate pine cone, megasporophylls spreading apart; *B*, megasporophyll and two seeds; *C*, a single seed with wing. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

A seed is therefore not a single reproductive body comparable to a spore or gamete. It is a body consisting essentially of a megasporangium with its surrounding integument; within which is the gametophyte generation or the remains of it; within which in turn is the next sporophyte generation in embryo form. A seed contains two entire plants, one parasitic upon its parent; and that parent itself is parasitic upon its investing coats, which are parts of a previous plant.

The integument is now known as the *seed coat.* It becomes very tough and hard, and protects the more delicate inner parts against drying and against mechanical injury. In many kinds of pines, a part of the megasporophyll remains attached to the ovule,

forming a delicate wing, which, when the seed falls, catches the air, thus often causing the seed to be carried to some distance; otherwise the seed would fall so near the parent tree that it would suffer, in its later development, from the shade. The seed may remain dormant for some time—living upon the large amounts of stored food contained in its megagametophyte.[3]

200. Seed Germination.—Under certain conditions the seed germinates—that is, the embryo resumes growth. The hypocotyl elongates, using food from the megagametophyte, the seed coat cracks, and the micropylar end of the hypocotyl emerges. Its tip responds positively to gravity, grows down into the soil, and becomes a primary root. Meanwhile the rest of the hypocotyl continues to elongate, and, as one end is fast in the soil and the other in the seed coat, it arches, frequently lifting the seed up. The final result of this growth is that the cotyledons and epicotyl are pulled out of the surrounding tissues, and soon grow into a vertical position; the seed coat, nucellus, and what is left of the megagametophyte drop off, die, and decay. The cotyledons spread apart and become green, and begin to manufacture food. This embryo sporophyte is now an independent plant. The epicotyl begins to grow, and forms all the parts of the plant which we usually see above the ground—stem, branches, leaves, cones, and so forth—except the base of the stem, which originated from the hypocotyl. The cotyledons eventually are shed.

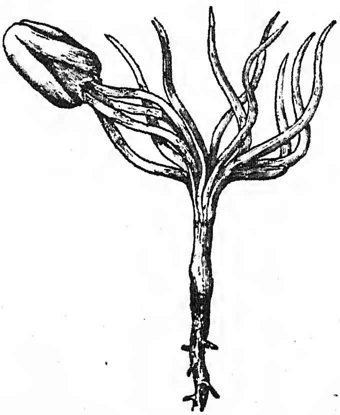


FIG. 277. A germinating pine seed; only part of the root is shown. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co).

201. Time Relations in the Reproduction of the Pine.—Reproduction of the pine[4] by seeds, which has been described here in pages which require an hour or thereabouts for careful reading

[3] The megagametophyte of a pine seed is often called the endosperm; but this term should be reserved for the endosperm of an Angiosperm seed, which, though similar in function, has an entirely different origin.

[4] Reproduction by seeds involves the life cycle from sporophyte through the gametophytes to the new sporophyte. It therefore includes reproduction by spores and by gametes.

actually extends over a period of three or four years. This is shown in the following table arranged from the observations of Ferguson on the white pine, *Pinus Strobus*.

WHITE PINE (*Pinus Strobus*)

First year	
Spring — carpellate cones appear—ovules formed.	*Spring* — staminate cones appear—microspores formed—pollen grains develop.
POLLINATION	
Summer — megaspore develops—immature megagametophyte.	*Summer* — pollen tube formed, body cell and stalk cell formed and move into pollen tube.
Winter	*Winter*
Second year	
Spring — megagametophyte matures—archegonia develop—megagametes formed.	*Spring* — body cell forms microgametes—pollen tube reaches archegonia.
FERTILIZATION	
Summer and *fall* — seed matures and is dispersed.	
Winter	*Winter*
Third year	
Spring — seed germinates.	

202. **Significance of Details of Reproduction.**—To the average person the complicated series of events detailed in describing the reproduction of the pine by seeds may appear to be a matter of academic interest only. Yet it must be borne in mind that since natural vegetative reproduction in the pines is extremely rare it is upon seed production that the continued existence of this valuable and important group of plants depends, and that before this can occur each one of the steps in reproduction by seeds must be successfully completed. Before there can be new pine trees to take the place of those which die naturally or are used by man there must be developed on the old pine trees carpellate cones with ovules containing megagametophytes, archegonia and megagametes, and staminate cones containing functional pollen grains; pollination must occur; the pollen tubes must form and the mature microgametophytes with microgametes develop; fertilization must occur; the zygotes must develop into embryo sporophytes within completely formed seeds; and finally the seeds must be distributed

and germinate. It was by a series of events similar to this that a single cell (the zygote) half the size of a pin head was formed and began its development in the ovule of a *Sequoia* cone on the western coast of America 1,000 years before the birth of Christ; and grew into a giant *Sequoia* tree which stands there now, 300 feet high, 30 feet in diameter, and consisting of billions of cells.

In a pine, failure to complete any one of the steps from the beginnings of the carpellate and staminate cones to the germination of the seed means failure to maintain its kind. Such failures occur. Through Missouri, Illinois and into Ohio stretches a belt of country where the only native gymnosperm is the red cedar, *Juniperus virginiana*. South of this belt are forests of pine—north of it are forests of pine. In this section pines planted as seedlings grow and flourish, but few young seedlings appear beneath them. Some item or combination of items of the environment (climate, soil or competing organisms) prevents the completion of one of the steps in reproduction by seeds and as a result pines do not comprise a part of the native flora of this section. This indicates that relatively small changes in environment may prevent a particular plant species from maintaining itself naturally; for the environmental conditions in the pine forest regions are not so very different from those of the section referred to.

That such changes in the past have shifted or limited the distribution of a particular kind of plant or destroyed it completely is indicated by the remains preserved in the rocks as fossils. These show that many kinds of conifers which once flourished have disappeared as living plants entirely and that others which once occupied broad areas are found now in limited portions of the earth.

203. **Advantages of Seeds.**—The seed has had much to do with the success of the seed plants. It has many advantages over spores, zygotes, and the like. Its coat is frequently extremely tough and impervious, so that the contents are protected from mechanical injury and desiccation. The low water content of a seed enables it to endure long periods at low temperatures. It contains large quantities of stored food, which enable it to remain dormant and still living for a long time, and which supply the requisite energy for germination when the time comes. And, finally, when the seed germinates no long time is necessary for the first root and leaf to appear—for they are already present in the ungerminated seed; differentiation has already taken place in

advance of dormancy and germination. Many seeds, like those of the pine, possess structures of various kinds which favor their dispersal, so that there is a good chance for germination of at least a few seeds from each parent.

204. **Summary.**—We may sum up the characteristic features of seed plants, as illustrated by the pine, as follows:

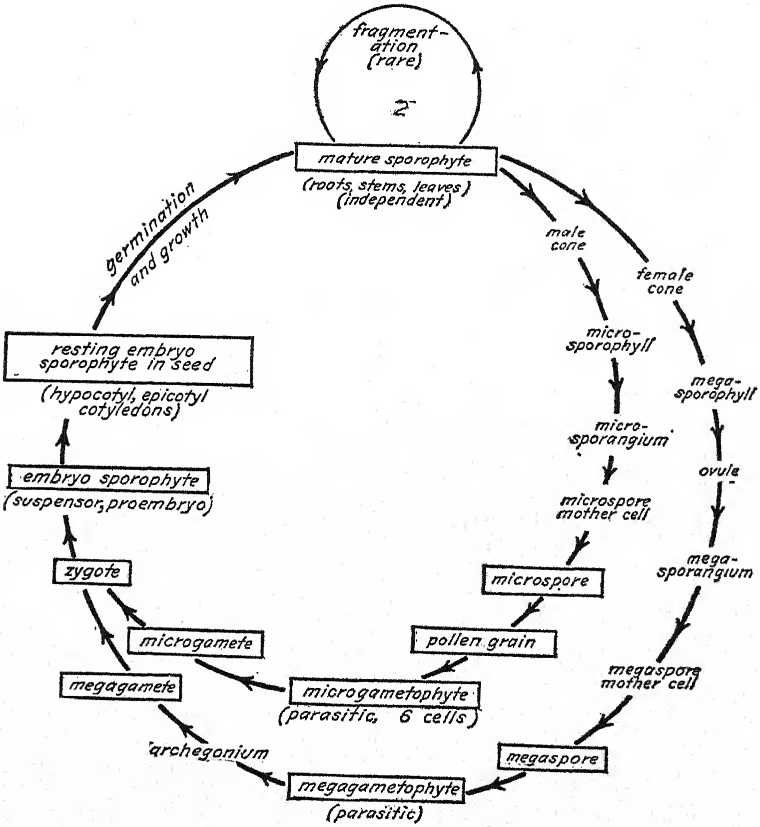


FIG. 278. Diagram of the life-cycle of the pine.

Heterospory—two visibly different kinds of spores are produced, forming two kinds of gametophytes, each forming only one kind of gamete.

The gametophytes are very small parasitic plants. The megagametophyte passes its entire life within the ovule of the sporophyte;

the microgametophyte commences development within the microsporangium, is then transferred to or near the ovule (pollination), and there completes its growth.

Gametes are brought together by means of a special canal, the pollen tube, which contains the microgametes and leads to or near the megagamete.

The zygote germinates to form an embryo which is parasitic upon the preceding generation, and which, after some growth, becomes dormant. The whole ripened ovule, containing the embryo, together with a part of the megagametophyte, then is separated from the parent, and is called the seed.

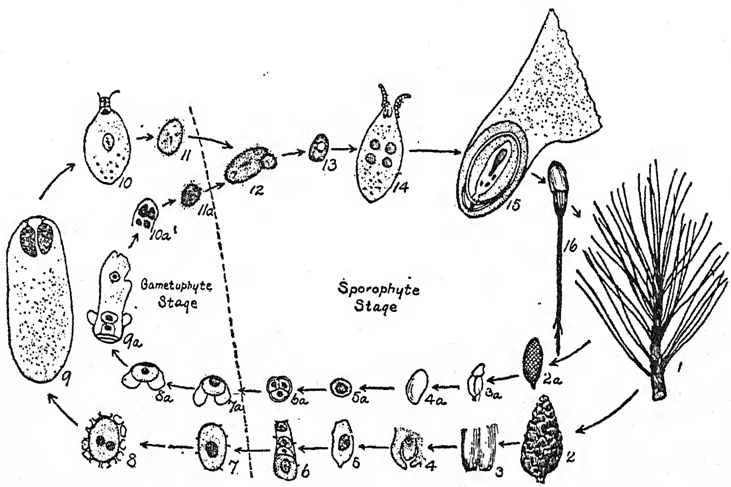


FIG. 279. Diagram of the life-cycle of the pine. (After Schaffner from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

The sporophyte is a leafy structure.

Spores are borne in sporangia in sporophylls as in a fern; but the sporophylls differ from vegetative leaves and are grouped on a specialized branch.

Of these characteristics, some are shared by the Pteridophytes, or by some of them. The outline of the life cycle is just the same as that of the Bryophytes and Pteridophytes. In addition to the formation of seeds the greatest differences between Spermatophytes and other plants are the retention of the megagametophyte in the megasporangium, and the process of pollination and pollen tube development.

CHAPTER XXIII

Angiosperms—Seeds, Seedlings, and Mature Plants

In the group known as the Angiosperms are included the plants we commonly think of as the flowering plants. These are, of course, to us the most familiar of all plants. Roses, lilies, daisies, geraniums, and all the inhabitants of our gardens; potatoes, tomatoes, oranges, apples, peas, beans, beets—all our familiar fruits and vegetables; and many others that one does not always think of as bearing flowers—trees, grasses, rushes. The number of kinds of Angiosperms is immense,[1] and they present an enormous variety of different forms, sizes, colors, manners of growth, and so forth.

Throughout this wealth of diverse forms runs a thread of similarity: the manner of reproduction. They all bear flowers, from which are formed fruits and seeds. A beautiful cluster of roses does not resemble, at first glance, the feathery top of a grass, which also is a group of flowers; but, if both are dissected, their reproductive parts are found to be very similar in structure and function. So also with the seeds. Furthermore, the latter are essentially the same structures as the seeds of a pine or other Gymnosperm. The general scheme of reproduction, then, is nothing new. We find features that remind us of the pine, of the club moss, of the fern. It is only in details of form and function that we find differences between this group and the others, and between the members of this group.

Seeds and Seedlings

The seeds of Angiosperms vary in size from those of the orchids, which are dust-like, to that of the cocoanut, which includes all but the shell of that common esculent. The majority of seeds range from the size of a small shot to that of a marble. They also show considerable and characteristic differences in shape, surface

[1] It is estimated that there are 130,000 known species of Angiosperms; more than half the total number of species of all known plants. This estimate does not include all the known races or varieties of species—such as different varieties of apples, wheat, etc.

markings and colors. So distinctive are the differences in the morphology of seeds that many kinds of plants can be identified by their seeds, an important consideration in the determination of the presence of undesirable weed seeds with those of garden or field crops.

205. Parts of a Seed.—A seed is, as already explained, essentially an *embryo plant*, an immature sporophyte, containing or surrounded by a tissue rich in stored food, the whole enclosed by an outer coat. Some seeds consist of but two parts, an embryo sporophyte enclosed by a *seed coat* (*testa*). Others contain an embryo sporophyte surrounded by a tissue containing stored food material, the *endosperm*, the whole covered by a seed coat. A few seeds are composed of four parts—the seed coat, within which is a tissue derived from the megasporangium and called the *perisperm*, which in turn encloses the endosperm and embryo sporophyte. The embryo sporophyte is made up of a short stem and one or two seed leaves called cotyledons. The portion of the stem located above the point of attachment of the cotyledons is called the *epicotyl* or *plumule*. In some seeds it is composed partly of true leaves, in others it is an undifferentiated knob of embryonic tissue. The epicotyl develops into the chief portion of the main stem of the mature plant and forms the branches, leaves and flowers. The portion of the stem below the cotyledons is called the *hypocotyl*. It develops a root at its lower end; in some seeds the young root has already differentiated. We may list the major parts of the seed as follows, bearing in mind that one or more of these parts may be lacking in the seeds of some kinds of plants:

Parts of the Angiosperm seed
- seed coat (testa)
- perisperm
- endosperm

$$\text{embryo sporophyte}\begin{cases}\text{root}\\ \text{stem}\begin{cases}\text{epicotyl (plumule)}\\ \text{hypocotyl}\end{cases}\\ \text{cotyledons}\end{cases}$$

206. Types of Seeds.—The water lily seed is an example of the rather unusual type with all four of the main parts mentioned above. Most of the space within the seed coat is occupied by the perisperm. At one end is the embryo sporophyte surrounded by a thin layer of endosperm The *Canna* seed is of the same sort.

The mature persimmon seed lacks the perisperm; it is made up of a seed coat, endosperm and embryo sporophyte. If we dissect a persimmon seed we find in the center a spoon-shaped embryo

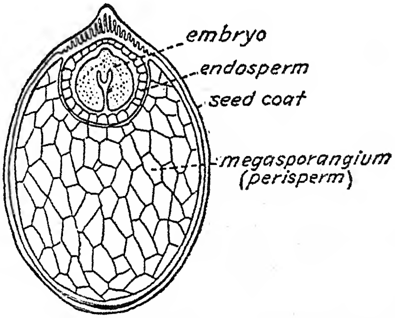


FIG. 280. Longitudinal section of a seed of a water lily. (After Conard from Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

sporophyte. The handle of the spoon is the hypocotyl, the bowl of the spoon is two thin cotyledons lying face to face. Between the two cotyledons is a minute cone-shaped knob of embryonic tissue, the epicotyl. Surrounding the embryo sporophyte is a rather hard mass of cells, the endosperm, which contains stored food; and

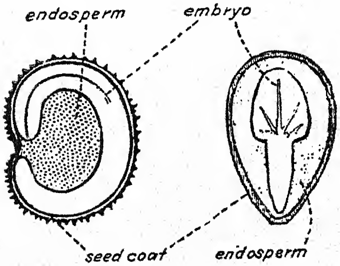


FIG. 281. Left, section of the seed of corn cockle (*Agrostemma*); right, section of the seed of *Oxalis;* both enlarged several times. (From Figuier, *The Vegetable World*, Hachette et Cie.)

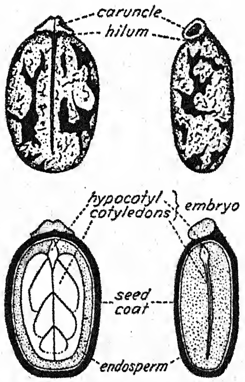


FIG. 282. Seed of the castor bean. Above, entire seeds; below, median longitudinal sections.

around the endosperm is a tough brown skin, the seed coat. The seeds of many Angiosperms are constructed on this general plan and have these same three parts. Common examples are those of the castor bean, flax, *Oxalis*, and corn cockle. The seed coat is often marked by a scar, the *hilum*, which indicates its place of attachment to the sporophyll. The micropyle also may be visible as a small spot, often near the hilum.

The persimmon seed is almost exactly like that of a pine. The difference is that the food-containing tissue of a pine seed is, as we have seen, a megagametophyte. In an Angiosperm seed the endosperm, if present, is *derived from* the megagametophyte, but is not the gametophyte itself. The exact manner of its formation will be discussed later. The perisperm, if present, is derived from

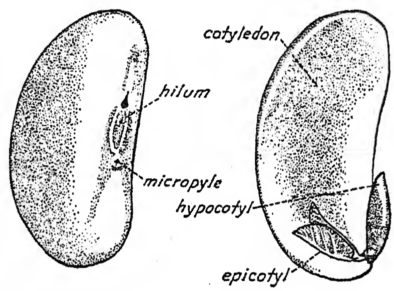


FIG. 283. Bean seed. Left, entire seed; right, embryo with seed coat and one cotyledon removed.

the megasporangium, which is visible in a mature pine seed only as a thin brown membrane around the megagametophyte. In no Angiosperm seed does the megagametophyte persist and contain stored food.

If now we study the seed of a plum (it is found inside the stone), we find only an embryo immediately surrounded by a thin seed coat. The same is true of a bean or a peanut seed, found in the pod or husk respectively. No endosperm or perisperm is present. At least one of these tissues was present when the seed was small; but was absorbed by the embryo in its growth, so that the latter now contains within itself the food formerly stored in the endosperm. This is evident in such a seed as that of a peanut; the food is stored in the two cotyledons, which become swollen and form the familiar halves into which the seed breaks so readily.

One very common and very large family, the grass family, which includes not only the grasses of lawns and meadows, but also wheat, oats, corn, rice, and our other cereals, has an embryo peculiar in that it has only one cotyledon. The embryo is thus a lopsided structure, made up of epicotyl, hypocotyl, young root, and a single cotyledon on one side (though on the embryos of some members of the grass family a second cotyledon, in a rudimentary form, is found opposite the normal cotyledon; this is known as the *epiblast*). The cotyledon is large and fleshy and so shaped that it enfolds the other parts of the embryo more or less completely.

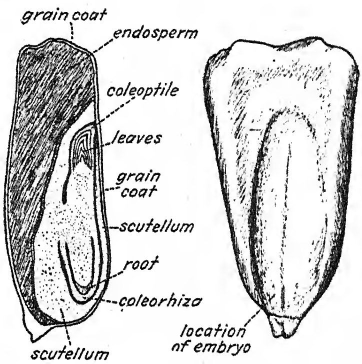


FIG. 284. Corn grain. Left, longitudinal section, perpendicular to the broad face of the grain; right, surface view.

The possession of only one cotyledon is characteristic of several other families, such as the lilies, the orchids, and the palms. All such plants are spoken of as Monocotyledons. The remaining Angiosperms have two cotyledons, and are called Dicotyledons. Other differences in the structures of these two groups have been mentioned earlier.

207. Dormancy of Seeds.—Some kinds of seeds germinate at once if placed in a moist place; others will not do so until after a period of dormancy.[2] Different seeds lie dormant for different lengths of time. Almost all seeds may be kept in a dry place for many months or years, and remain alive and capable of growth.

208. Germination.—When a seed germinates, the first thing that takes place is the absorption of water. This causes the enlargement of the cells of the embryo, and, to some extent, of other parts of the seed also. At the same time food, either in the

[2] The cause of dormancy in seeds varies with the kind of seed. In many sorts it is due to the seed coat, which is either too strong for the embryo to break or is impermeable to gases or water. This is true of some of the seeds of many legumes such as alfalfa, sweet peas and the clovers. Before such seeds can germinate, changes must take place in the seed coat which weaken it or render it permeable. Cracking the seed coat or nicking it with a file or knife will shorten their dormant period. In other seeds the cause of dormancy is within the embryo and changes, included under the term *after-ripening*, must take place in the embryo before it will grow.

endosperm or in the cotyledons (and in the perisperm, when this tissue is present), is digested and translocated to the enlarging regions; where some of it is built into new protoplasm and new cell walls; and some of it is respired and liberates the energy which is involved in the performance of such functions. The germination of seeds is usually marked, therefore, by the appearance of considerable quantities of enzymes.[3] In the grains, where the food is stored in the endosperm, the production of enzymes is a special function of the surface layer of the single large cotyledon (*scutellum*). This is known as the *epithelial layer* of the cotyledon.

The intake of water by the embryo is accompanied by the beginning of cell division, particularly in the embryonic lower end of the hypocotyl (the end farthest from the cotyledons). The formation of new cells, their enlargement and differentiation,

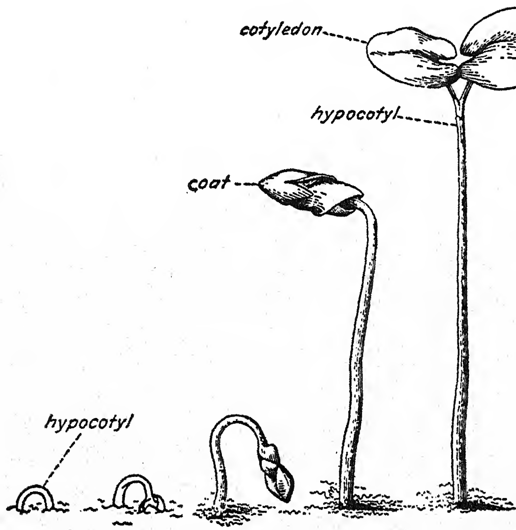


Fig. 285. Germination of a buckwheat grain. (From Atkinson, *First Studies of Plant Life*, Ginn & Co.)

proceed in the same way as in any young root; the result is a rapidly growing primary root, which pushes its way out of the seed, responds positively to gravity, and penetrates the soil. Root hairs are formed, more water is absorbed and travels up the differentiating stele; branch roots grow out from the pericycle.

[3] Commercial "diastase of malt" is prepared from germinated barley and contains the enzymes from the germinating seeds together with some inert material.

The further history of the embryo varies considerably with the kinds of seeds. In many kinds of seeds it proceeds substantially as in a pine seedling. In the buckwheat embryo, for instance, after the primary root has emerged, the upper part of the hypocotyl (the part near the cotyledons) elongates, and the cotyledons themselves begin to enlarge. Since one end of the hypocotyl has become a root which is anchored in the soil, and the other end bears the cotyledons which are still fast in the endosperm, this elongation results in the formation of an arch, which pushes up through the surface of the soil. Soon, as a result of the withdrawal of food from the endosperm, the latter becomes flabby and no longer enfolds the cotyledons so tightly; so that further elongation of the hypocotyl and cotyledons pulls the latter completely out of the outer coat which, together with remnants of the endosperm, is left behind in the soil. Owing to its positive reaction to light and

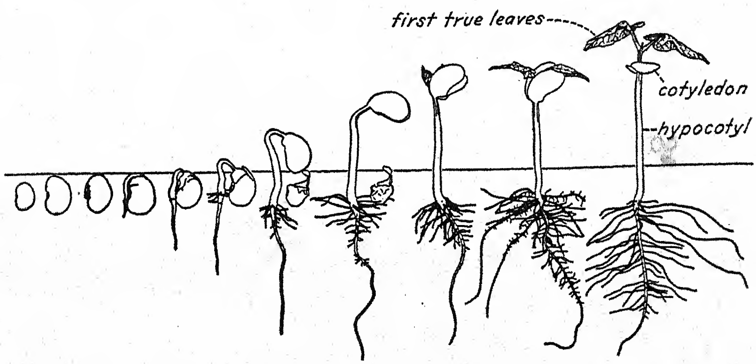


FIG. 286. Germination of a bean seed. (From Ganong, *Textbook of Botany for Colleges*, copyright 1916 by The Macmillan Company. Reprinted by permission.)

negative reaction to gravity, the hypocotyl now straightens up, the cotyledons on its tip spread out and begin photosynthesis, and the young plant is self-supporting and independent—a young buckwheat plant with primary root, primary stem (hypocotyl and epicotyl), and primary leaves (cotyledons). The epicotyl, that embryonic region at the upper end of the hypocotyl and between the bases of the cotyledons, now begins growth, and continues as does any stem tip, taking the form of a bud, developing continually into new stem and leaves, until we have finally a mature buckwheat plant. The cotyledons, after their period of usefulness, wither and

fall. This history is essentially the same as that of a pine embryo; it holds also for the germination of the seeds of castor beans, squashes, persimmons, and many other Angiosperms.

The bean seed germinates in much the same way. The embryo of this plant, however, differs from that of the persimmon or buckwheat in having two very large fleshy cotyledons filled with stored food; as these emerge from the soil on the end of the elongating hypocotyl they are furnishing food to the growing parts

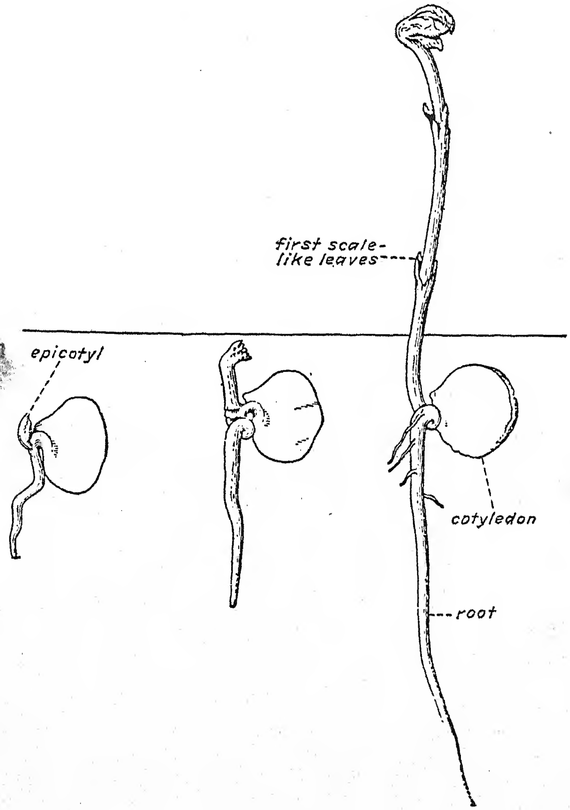


FIG. 287. Germination of a pea seed—one cotyledon removed. (From Atkinson, *First Studies of Plant Life*, Ginn & Co.)

and consequently become shriveled; they carry on little photosynthesis before they fall to the ground. In this type of embryo the embryonic regions on either end of the hypocotyl have developed

the primary root and the first bud before the seed became mature; so when the seed germinates these parts are very soon apparent and the young plant ceases at an early age to be dependent for food upon its cotyledons.

The pea embryo has a simpler method of germination. The first root is formed as usual; but the upper end of the hypocotyl does not then elongate and carry the cotyledons into the air; instead the cotyledons remain beneath the soil, and the first part to emerge above the ground is the epicotyl, which, like that of the bean, had already differentiated its first few leaves before the seed became mature. The first leaves of a pea plant that are seen are not the primary leaves (cotyledons); these remain underground. The cotyledons are large and fleshy like those of the bean and are of the same use to the young plant.

This type of germination is seen also in the corn grain (or in any member of the grass family). The embryonic lower tip of the hypocotyl is already, in the dormant seed, differentiated into a primary root, protected by a root cap and by a special sheath, the *coleorhiza*. The primary root is the first thing to grow in germination; it bursts through the coleorhiza and penetrates the soil. The epicotyl, which was already differentiated, in the dormant grain, into the first bud of embryonic stem and leaves, pushes up through the soil, protected by a special covering, the *coleoptile*, out of which it presently grows. The cotyledon is not carried up into the air. Its use to the rest of the embryo has already been mentioned. It helps in making available the food stored in the endosperm (commonly in the form of starch and other insoluble foods); it is chiefly a digestive and absorptive organ.

As the primary root of the corn grain continues growth, many branch roots are formed. Roots develop also from tissues at the junction of epicotyl and cotyledon. We call roots which develop neither from the tip of the hypocotyl nor from other roots *adventitious* roots. As the bud which arose from the epicotyl pushes up, its leaves push through the coleoptile and spread their blades to the air and light. The first leaves arise on the stem a short distance above the attachment of the latter to the cotyledon; the region between the cotyledon and this first node is called the *mesocotyl*. More adventitious roots develop at the upper end of the mesocotyl, that is, at the first node. Others develop later from nodes farther up the stem. Many roots usually develop from nodes above the

soil line; they are often known as "brace" or "prop" roots, since they seem to brace the stem at its base. The mesocotyl and all parts below it, including the primary root and its branches, usually decay, and the adventitious roots form the permanent root system

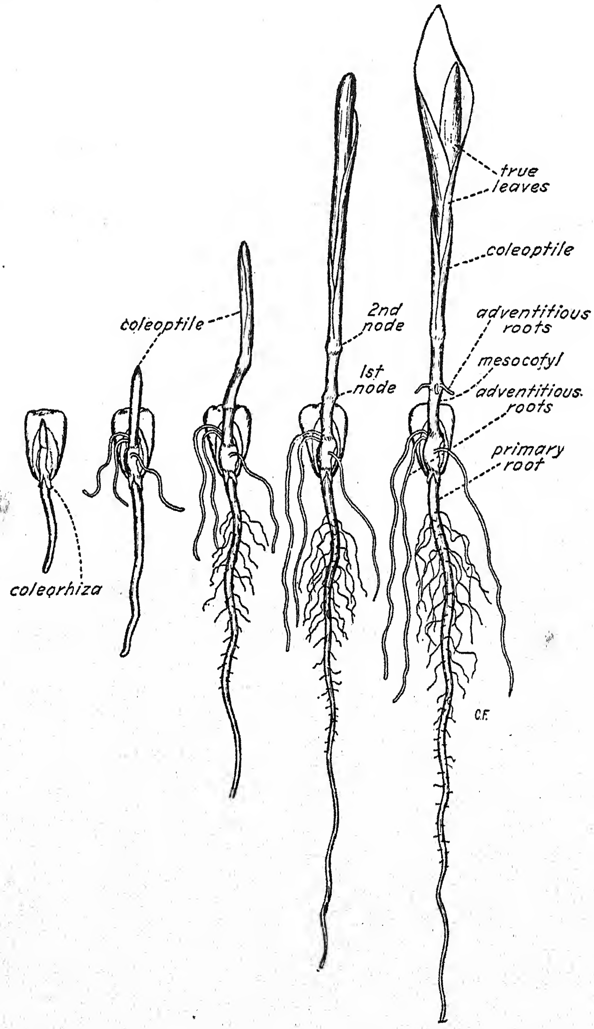


FIG. 288. Germination of a corn grain.

of the mature corn plant. The mature plant, therefore, develops from the epicotyl alone, other parts of the seed being only temporary in their usefulness; this recalls the history of the fern embryo,

where similarly the mature plant comes from one part of the embryo (the primary stem) and all other parts (primary roots and leaves, and foot) die after having served a period of usefulness.

In all these types of germination, it is noteworthy that the general functions of the different parts are the same. The epicotyl always becomes stem and leaves (sometimes roots also); the end of the hypocotyl farthest from the epicotyl always forms a primary root with its branches; the hypocotyl itself may be beneath the ground or partly above it—forming the transition between root and stem; and the cotyledons always aid in the nourishment of the embryo, whether by manufacturing food, by storing food, or by digesting and absorbing food stored elsewhere.

The Mature Plant

It is not necessary here to discuss in detail the structures and activities of a mature flower-bearing plant, since these have already been described to illustrate plant life in general. The root and stem differentiate into the epidermis, the cortex, and the stele with its xylem and phloem, each of these containing the sorts of cells characteristic of it—parenchyma, vessels, sieve tubes, and so forth. The leaves differentiate into epidermis, veins, palisade tissue and spongy tissue. Growth continues at the root tip, at the stem tip (where a bud is the result), at the tips of all branch roots and stems, in the cambium and in the cork cambium of root and stem.[4] Water is absorbed, passes up the root and the stem to all parts. Food is manufactured in the leaves, travels out to the other cells, is built into protoplasm and cell walls, or respired. All the wonderful and complex interactions between the protoplasm and its environment—all that we sum up in the word Life—are taking place.

This story is much the same for most Angiosperms. But the Angiosperms are a large group of very diversified plants. Their size varies from that of the little floating *Wolffia* (duckweed), smaller than a pinhead, to that of the giant *Eucalyptus* tree, several hundred feet tall. Most of them are land plants, but some (such as *Elodea*) have invaded the domain of the algae and live in the water; others (such as the cacti) can exist in the arid desert. Most of them contain chlorophyll and construct their own food from carbon dioxide and water, but some are deficient in chlorophyll or lack it entirely, and live as parasites (such as mistletoe and

[4] Except in Monocotyledons, which lack cambium.

dodder) on other plants or as saprophytes (such as Indian pipe) in the leaf mold of a forest floor. Some of them have life periods measured in centuries, others complete their entire life cycle in a

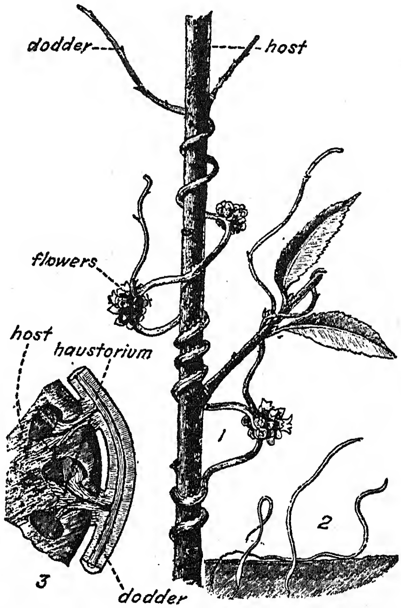


FIG. 289. Dodder, a parasite. *1*, habit sketch; *2*, seedlings of dodder; *3*, section through stem of host and parasite showing haustoria of dodder reaching the fibro-vascular bundles of host. (From Strasburger, Noll, Schenck and Schimper, *Lehrbuch der Botanik*, Gustav Fischer, Jena.)

few weeks. An examination of the leaves, stems, and roots of different kinds of Angiosperms emphasizes their diversity.

209. **Differences in Leaves.**—Leaves vary greatly in size, in shape, in thickness and texture, in the character of their margins, in the arrangement of their veins, in the extent to which they are lobed or divided. A banana leaf may be nine feet long and two feet wide, while the leaves of the little bluets that produce their tiny blue flowers early in the spring measure only one-fourth by one-eighth of an inch. Between such extremes there are all intermediates. A geranium leaf is about as wide as it is long, while a grass leaf may be twenty times as long as wide. The leaves of many kinds of plants are divided into a flat extended blade and a stalk-like portion, the petiole, at the base of which are two ap-

pendages called *stipules;* while others have leaves which lack stipules, or which consist of a blade alone, or of the petiole, with or without stipules, and no blade.

FIG. 290. Indian pipe (*Monotropa*), a saprophyte.

The form of the leaves is often markedly influenced by the environment in which they develop. The mermaid plant (*Proserpinaca*) grows commonly submerged in water; the upper parts, however, may emerge into the air. The leaves of the submerged

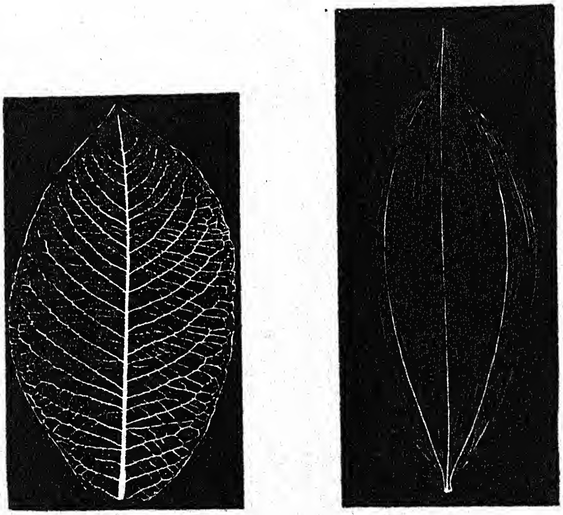


FIG. 291. Venation of leaves. Left, a dicotyledonous plant; willow, *Salix grandifolia*. Right, a monocotyledonous plant; lily of the valley, *Convallaria latifolia*. (From Sachs, *Physiology of Plants*, Clarendon Press, Oxford.)

portion are usually finely cut into hair-like parts in arrangement like the delicate parts of a feather; the leaves formed in air may be of the type familiar to us in many land plants—a broad blade, slightly toothed. This arrangement may be completely reversed by growing the plant first in a comparatively dry atmosphere and later (while the upper leaves are forming) in a very moist environment.

Almost every possible shape is illustrated by Angiosperm leaves; many grass leaves are linear, that is, long and narrow with the two margins almost parallel; the elm leaf is more or less oval, the nasturtium leaf circular, the geranium leaf kidney-shaped, the leaves of willows lance-shaped. Many leaves are thin and soft to the touch, often being covered with hairs, as is the geranium leaf; contrast with this the leaf of the rubber plant, often used for interior decoration, which is thick, firm, and waxy on the surface. Some leaves are sharply toothed on their margins, while others are smooth or merely wavy; the elm leaf bears sharp teeth, the lily leaf is smooth in outline.

Many leaves are lobed, with either sharp or rounded lobes, such as are seen in the leaves of soft maple and white oak respectively. Other kinds of leaves are divided into several small *leaflets*. The buckeye has such a leaf; it is made up of a petiole at the tip of which are usually five somewhat oval leaflets, these together making up the blade. In the leaf of the locust the stalk is prolonged into a long axis, along the sides of which many small leaflets are arranged in pairs. Such leaves may sometimes be mistaken for branches bearing small leaves; but at the bases of the apparent small leaves are no axillary buds, while at the base of the apparent branch on which they are borne there is an axillary bud (or a branch), which shows that the apparent branch is a petiole and the apparent leaves are all parts of the same leaf. Such divided leaves are often spoken of as *compound*. The two types illustrated by the buckeye and the locust are known respectively as *palmately compound* and *pinnately compound* leaves. There are other respects in which leaves vary in external appearance; but enough has been said to illustrate the immense diversity of types within this group of plants.

Leaves may be so greatly modified that they perform very different functions from those (for example photosynthesis) common to most leaves. The bud scales of resting buds are modified leaves;

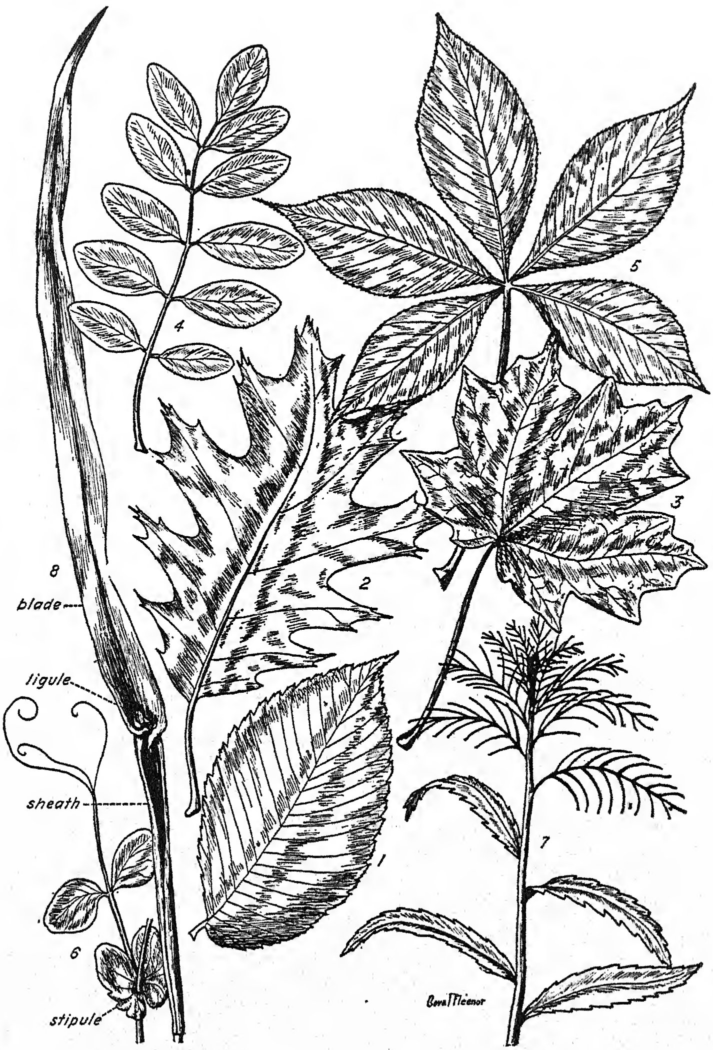


FIG. 292. Types of leaves. *1*, *2*, elm leaf and oak leaf, both pinnately netted veined; *3*, maple leaf, palmately netted veined; *4*, black locust leaf, pinnately compound; *5*, buckeye leaf, palmately compound; *6*, a pea leaf, with stipules, tendrils, and two unmodified leaflets; *7*, portion of a plant of the water mermaid, *Proserpinaca*, with upper leaves modified by immersion in water; *8*, grass leaf.

they protect the inner tender parts of the buds from loss of water. The compound leaf of the garden pea possesses certain leaflets which are not blade-like but hair-like, and which have the property of coiling around objects with which they come in contact and so supporting the entire plant. Such parts (they are not always leaves or parts of leaves) are called *tendrils*. The thorns on some cacti and on the barberry are modified leaves, which protect these plants from marauders (thorns also are not always leaves; the thorns of some plants are hairs or branches). The parts of the flower are considered to be modified leaves, and function in reproduction.

Some of the most striking leaf modifications are in the plants known as pitcher plants. In some of these the entire leaf has the

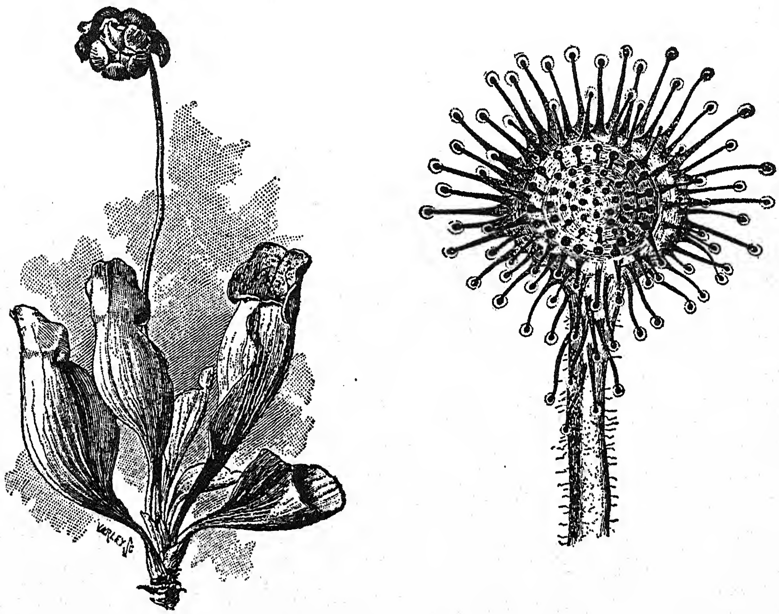


Fig. 293. Left, a pitcher plant, *Sarracenia;* one leaf is cut to show the cavity. Right, a portion of a leaf of the sundew, *Drosera.* (Left-hand figure from Bergen and Davis, *Principles of Botany*, Ginn & Co.; right-hand figure from Darwin, *Insectivorous Plants*, D. Appleton Co.)

form of a pitcher; in others the midrib is extended beyond the blade and is expanded into a similar hollow vessel. The interior cells secrete a sweetish nectar which attracts insects. These enter

the pitchers in search of the nectar, and are prevented from leaving by the structure of the inner wall of the pitcher, which is covered with tiny, slippery, wax scales, or with downward pointing bristles, or with cells whose lower edges project over the cells next below after the fashion of the tiles of a roof. In the bottom of the pitcher is a fluid, sometimes partly rainwater, sometimes formed by an excretion from the leaf; in this liquid the insects drown. Their bodies decay through bacterial action, and some of the products are probably absorbed by the plant.

There are other carnivorous plants, equally interesting and equally surprising in structure. The sundew has leaves covered with peculiar hairs, each of which consists of an upright stalk and an enlarged head. The head is covered with a sticky secretion, which entangles small insects alighting upon it. The heads of the hairs touched by the insect immediately begin to exude their secretion much more copiously; and some sort of stimulus is carried to all parts of the leaf, for the marginal hairs bend towards the center until they touch their prey; the hapless insect is in a few minutes entirely covered by these hair-like structures and immersed in the sticky secretion formed by them. The secretion that is formed contains a protein-digesting enzyme, and the products of the digestion of the insect body are absorbed by the leaf. The process of digestion may take several days; when it is finished the hairs slowly rise again to an erect position ready for a new victim. It is interesting that this complex set of reactions can be produced by touching the leaf with certain small solid, non-living bodies.

The plant known as Venus' fly-trap has a leaf blade of which the two halves fold together along the midrib when touched in a certain spot by an insect visitor or by any other object. The motion is rapid; the two halves come together in less than a second. At the margins of the blade are long teeth, which interlock when the blade is folded. Any insect which has the bad fortune to alight on one of these leaves is thus entrapped, the interlocking teeth at the margins preventing his escape. The leaf then secretes enzymes which digest its captive and absorbs the products. Such complex mechanisms excite our wonder; they resemble animal responses and mechanisms, and one is accustomed to think of plants as more placid and less bloodthirsty in their nutrition. It is well to remember that the responses and processes of ordinary plants, though not so spectacular, may be equally complex.

210. **Differences in Stems.**—Stems also show many modifications in form and function, though perhaps not to as great a degree as do leaves. Some stems form little or no secondary xylem or other thick-walled cells, are tender, and do not live through the winter. Our common weeds illustrate this *herbaceous* type of stem. Other stems form thick layers of secondary xylem and other thick-walled cells, and may endure for many years; these are the *woody* stems characteristic of our trees. Some stems are unable to stand erect without support, and twine around or attach themselves to other plants or to walls or rocks. Man uses this type of stem to his own advantage when he allows ivy to cover the walls of his buildings. We have already noticed the part played by the leaves of certain plants in supporting the stem. The tendrils of the grapevine, however, and those of the passion flower, are modified branches of the stem. Thorns, which are sometimes modified leaves, in other plants are modified stems, as in the hawthorn; they arise from the axils of the leaves as do other stems.

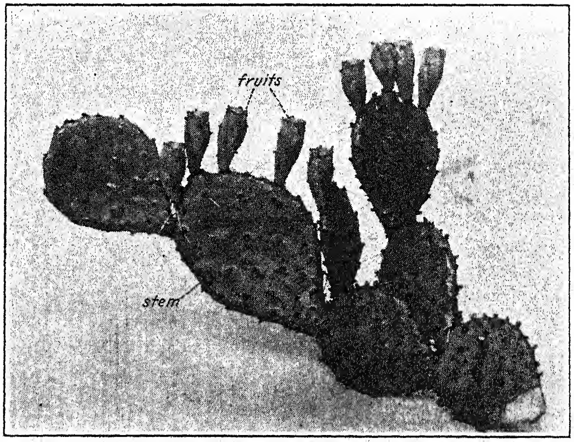


FIG. 294. A modified stem. The prickly pear cactus, *Opuntia*.

In some cacti (such as *Opuntia*) the stem is shaped like a chain of fat leaves, one growing from the point of another, and contains chlorophyll. Since this stem lacks leaves other than those modified into thorns, it is the only photosynthetic organ of the plant. It contains also many cells filled mostly with water. The

quantity of water is so great that one species of cactus (*Echinocactus Emoryi*) is of service to thirsty travelers crossing a desert where it grows. Many stems are underground, the only portion which stands erect being that branch which bears the flowers. Most of

FIG. 295. Papago Indian, near Torreo, Mexico, drinking the water which he has squeezed from the tissue of a cactus, *Echinocactus Emoryi*, by crushing it. (Courtesy of D. T. MacDougal.)

our grasses have underground stems (rhizomes). When branches of the underground stems become swollen with stored food, they are known as *tubers;* the Irish potato is an example. When, however, the entire underground stem is small, compact, and swollen, and contains stored food, it is spoken of as a *corm.* The so-called bulbs of crocus and Jack-in-the-pulpit are corms. The true bulb (examples of which are the hyacinth and the onion) is composed of both stem and leaves. The stem is small and flat or dome-shaped, covered on its upper surface with closely fitting fleshy leaves, and bearing roots on its lower surface. The thick

scale-like leaves contain stored food, by means of which the plant may remain alive under the ground for considerable periods; they also furnish the energy and building materials used in the production

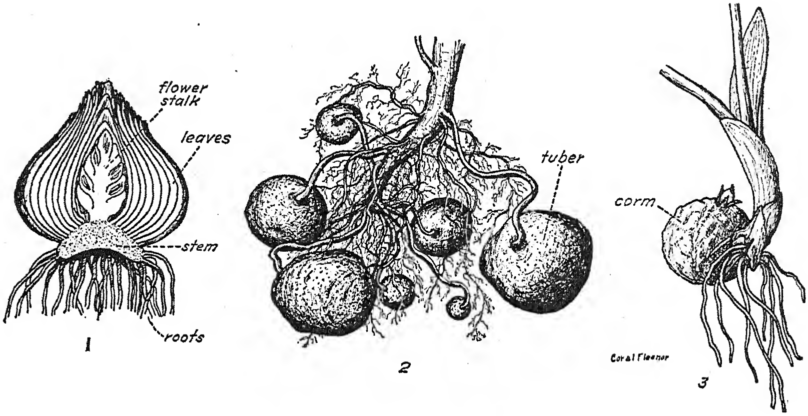


FIG. 296. Types of modified stems. *1*, bulb of hyacinth; *2*, tubers of Irish potato, *Solanum tuberosum; 3*, corm of Jack-in-the-pulpit, *Arisaema triphyllum.*

of the flowering branch, which arises from the tip of the flattish stem and pushes up between the storage leaves and so out into the air. In such plants as the carrot and the dandelion the stem is nothing but a crown (it is called a *crown stem*) on the top of the enlarged root; from it the leaves arise, and, later, the flowering branch.

211. **Differences in Roots.**—Roots also undergo modifications, though to a still smaller extent. The sweet potato is an enlarged branch root; the so-called bulb of a dahlia is a similar structure. The edible portion of a carrot or turnip is an enlarged tap root. Most roots grow into the ground, but some (adventitious roots) are produced from climbing stems, as in the ivy and poison ivy, and penetrate chinks in stones or bricks or adhere to the bark of trees. Some orchids which live on trees form aërial roots. The mistletoe and the dodder form roots which penetrate the tissues of the host upon which they live parasitically.

212. **Significance of Leaf, Stem and Root Modifications.**—Many of the differences in appearance which have just been described are of no known significance in the life of the plants concerned. We know of no advantage which the teeth on the margins of the

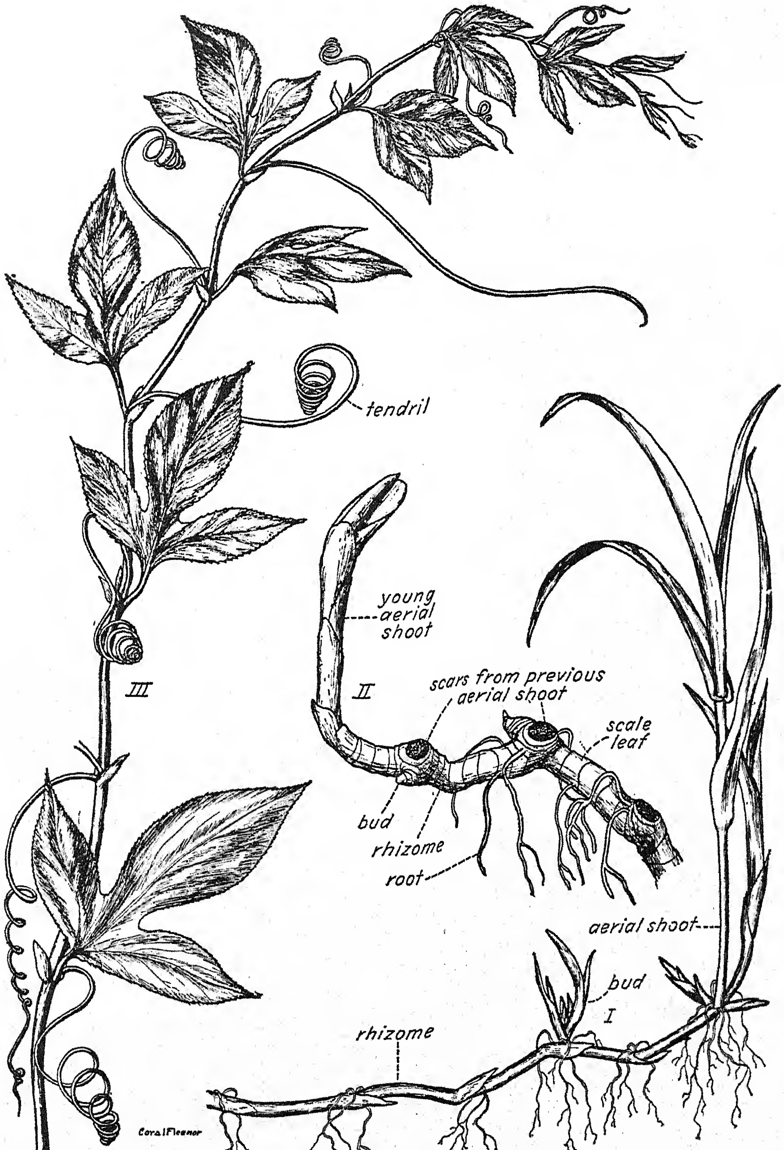


FIG. 297. Types of modified stems. *I*, rhizome of quack grass (*Agropyron repens*); *II*, rhizome of Solomon's seal (*Polygonatum commutatum*); *III*, stem of passion flower (*Passiflora incarnata*) with tendrils which are modified stems.

leaf confer on the elm tree; we are ignorant whether a lance-shaped leaf is more or less efficient in the performance of its functions than an oval leaf. It is true that the twining stem of a vine enables the plant to extend its leaves into the air without itself manufacturing the large amount of support tissue in its stem which would

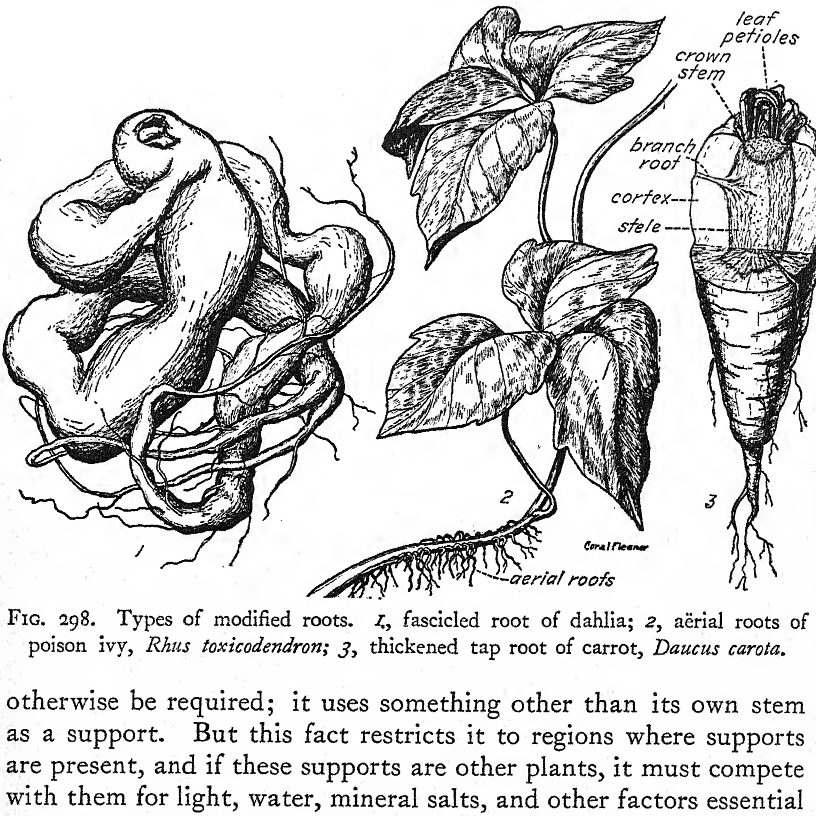


FIG. 298. Types of modified roots. *1*, fascicled root of dahlia; *2*, aërial roots of poison ivy, *Rhus toxicodendron*; *3*, thickened tap root of carrot, *Daucus carota*.

otherwise be required; it uses something other than its own stem as a support. But this fact restricts it to regions where supports are present, and if these supports are other plants, it must compete with them for light, water, mineral salts, and other factors essential to growth. Perhaps it is no better off than the plant which can stand alone and rise above other plants.

On the other hand, some of the features of leaves, stems, and roots are such that they affect the way of life of the plant very markedly and fit it to some particular environment or enable it to perform functions not found in other plants. Enlarged stems or roots such as are mentioned above store large amounts of food; they remain alive after the tops of the plants have been killed by the approach of winter or by other factors, and may produce new

shoots when conditions favorable to growth return. The common method of propagation of potatoes depends, not upon seeds, but upon pieces of tubers. The peculiar stems and the absence of green leaves in the cacti enable them to live in deserts (by reducing their transpiration while at the same time permitting photosynthesis) where most other plants cannot live, and also render them unfit to compete with larger and more rapidly spreading plants in moister regions. And finally such extraordinary plant structures as the leaves of the pitcher plants, sundews, and Venus' fly-traps certainly effect a large difference between their nutrition and that of ordinary plants; because of their protein diet they may be, to some extent at least, independent of the nitrates and other salts in the substrate upon which other plants are dependent.

All of these modifications and peculiarities of the leaves, stems, and roots of Angiosperms, besides being of interest to a curiosity hunter, point toward general conclusions of some significance. First, Angiosperms grow in all sorts of situations and climates, from the sands of the desert and the rocks of the mountains to tropical ravines and the waters of lakes and streams; and in each sort of environment we find plants having structures particularly fitted to that environment, which enable those plants to live there where others would die and which to a large degree restrict them to that sort of a situation. Second, even in the same environment, different plants have different structures, and so function in different ways, have different periods of life, store their food differently, and so forth; a tree, a grass, and a violet may all grow close together; yet they differ not only in external appearance but in very numerous and important details of structure. Each is adapted to its environment, but in a different way. Third, similar organs have developed in many different families of plants in different ways; the tendril, for instance, is in the grape family a modified branch of the stem, while in the pea family it is a leaf or a portion of a leaf. The underground storage organ of an Irish potato is a branch of the stem, while that of a sweet potato is a branch root.

How did these relations arise? What is the reason that a cactus is so beautifully fitted for life in the desert, *Elodea* so well suited for life beneath the waters of a stream? The problem is of the same nature as the problem of the complex structure of a single root or a stem; we have already seen that the various cells are beautifully adapted, both by their individual structures and

by their arrangement, for certain kinds of work performed by the organ in question. And in attempting the answer to this problem we must be careful not to give as a *reason* for the occurrence of such adaptations the fact that they are *needed;* this, of course, is not an explanation of the causes which have produced these modifications. There is nothing especially puzzling about the fact that of all the different kinds of plants those which grow in a desert are those which are adapted to arid conditions; if they were not, they could not live there. The real problem is: How did they become adapted? What is the origin of all the special structures and responses which we find in plants? This is the question of the origin of the different kinds of plants, and will be considered under the head of Biologic Evolution.

CHAPTER XXIV

Angiosperms—Reproduction

As we might expect from such a varied group, Angiosperms reproduce in a great variety of ways. But, when examined, their methods of reproduction prove to be the same as those of other groups of plants—by spores, by gametes, by vegetative structures—and differ only in detail.

Vegetative Reproduction

Many Angiosperms reproduce by means of their vegetative structures—stems, leaves, and roots. Many grasses have underground stems (rhizomes) which spread in all directions, sending up

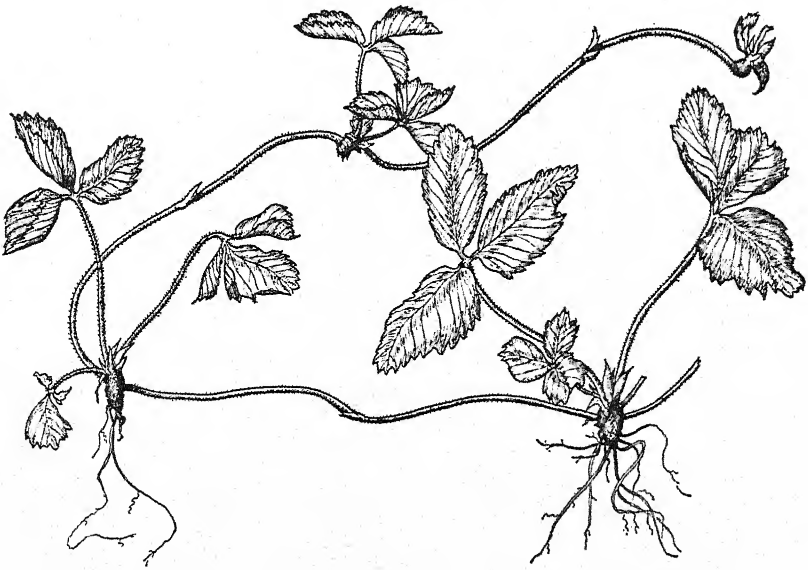


Fig. 299. Reproduction of strawberry by stolons. Notice that every other bud on the stolon grows into a new plant.

aërial shoots. The rhizomes become fragmented by various means (often the blade of the cultivator), and each portion may continue to live and grow. This is, of course, vegetative reproduction.

The tubers of a potato (which are enlarged underground branches of the stem) possess buds, which grow into new plants after the tubers have become separated from the rest of the parent plant; this is the common method of propagation of potatoes. The vegetative structure here is considerably specialized for reproduction, for it is much enlarged and contains much stored food, which is utilized by the new plant in its early growth. Strawberries and other plants have specialized stems called *stolons* or runners, which grow horizontally above the surface of the ground, and, where they touch it, form roots, leaves—entire new plants; the stolons

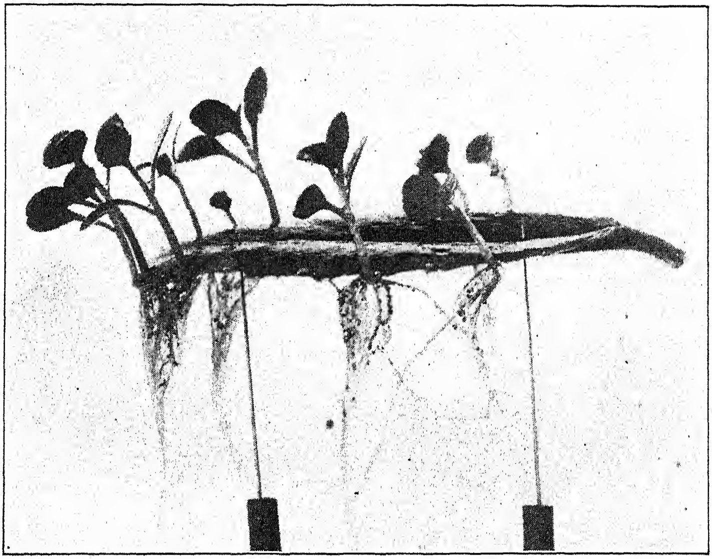


FIG. 300. Vegetative reproduction of *Bryophyllum calycinum*. New plants develop in the notches of the leaves. (Photograph by Naylor.)

themselves finally disappearing. *Bryophyllum* and *Begonia* (both tropical plants) are examples of plants which reproduce by means of leaves. If the leaves of *Bryophyllum*, for example, become detached and fall in a moist place, new plants grow from small buds which develop in the notches of the leaf margin. In *Begonia*, buds develop along the broken or cut edge of the leaf, as well as along the uninjured margin. Many kinds of vegetative reproduction are used in agriculture and floriculture. Geraniums and

many other greenhouse plants are propagated by "cuttings"; that is, a branch is cut from a plant and stuck in moist soil, adventitious roots develop from the lower end, and the branch becomes a new individual. Grafting is universally practised by fruit growers; branches are cut from old plants and joined to a stump already rooted, or to the branch of another plant; or buds are cut off and their bases inserted beneath the bark of another plant. The twig or bud cut off is called the *scion*, the plant upon which it

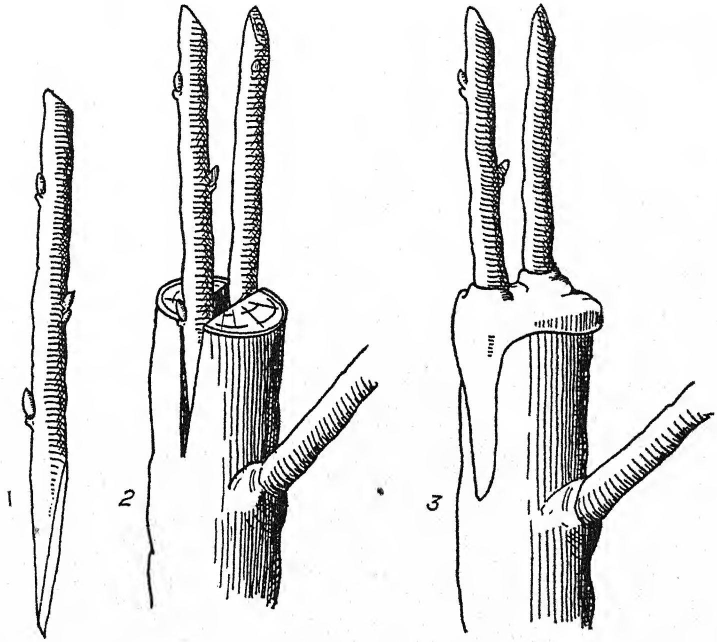


FIG. 301. Grafting. *1*, a scion; *2*, scions inserted into the stock; *3*, the union covered with wax.

is grafted the *stock*. The fundamental necessities in grafting are to use related plants, to join the cambium layers of stock and scion, and to prevent the drying out of the tissues at the point of union until the stock and scion have grown together. As a result of grafting we have a new individual formed from the ingenious union of the vegetative tissues of two (or more) old individuals.

Reproduction by Spores

213. The Flower.—A flower—a rose, for instance—does not much resemble a pine cone or a cluster of fern sporophylls. But it includes a group of spore-bearing leaves, and the spore production of Angiosperms differs from that of Gymnosperms and Pteridophytes chiefly in the detailed structure of the organs—sporophylls and sporangia—concerned. The flower is essentially a cluster of sporophylls on a central stem. The spores are borne in sporangia which are found on or in the sporophylls. There are two sorts of

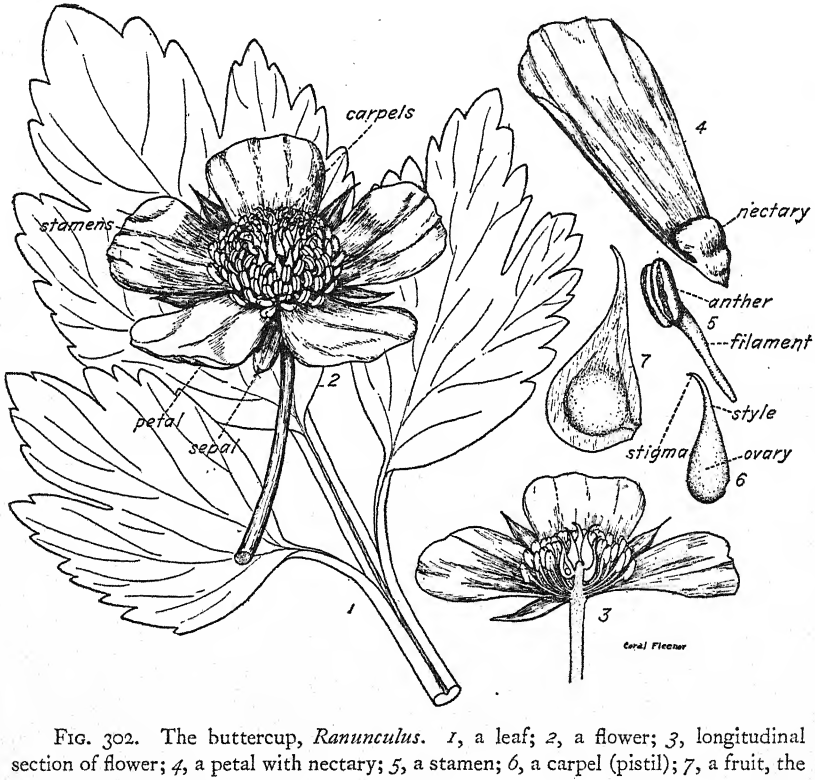


Fig. 302. The buttercup, *Ranunculus*. *1*, a leaf; *2*, a flower; *3*, longitudinal section of flower; *4*, a petal with nectary; *5*, a stamen; *6*, a carpel (pistil); *7*, a fruit, the ripened carpel.

spores, megaspores and microspores, as in the pine and in certain Pteridophytes, and each sporangium and each sporophyll normally bear only one sort of spore; consequently we may call these parts mega- and microsporangia and mega- and microsporophylls.

As an example which illustrates all the parts of an ordinary flower we may consider that of the buttercup. The most conspicuous parts of the flower are the five fairly large yellow *petals* arranged in a circle (together composing the *corolla*). At the base of each petal is a small gland (a *nectary*) which secretes a sweet liquid called *nectar*. Just below and outside the circle of petals is a like number of *sepals*, smaller than the petals and green (together composing the *calyx*). The petals and sepals together are called the *perianth*. Within the circle of petals are numerous *stamens* each consisting of a delicate stalk, the *filament*, capped by a yellow oblong head, the *anther*. In the center of the flower are a number of *carpels* or *pistils*. Each of these is somewhat pear-shaped, the enlarged basal part (*ovary*) tapering upward into a slender portion (*style*), the upper end of which (*stigma*) is enlarged and sticky.

The arrangement of these parts is best observed if the flower is cut longitudinally through the center. It is then easy to see that the stalk of the flower, the *pedicel*, terminates in a knob-shaped portion to which are attached the various floral parts. The sepals and petals grow laterally from this pedicel tip (called the *receptacle*) a short distance below its end; the remaining part of the receptacle is covered with the stamens and carpels.

214. Flower Parts Considered as Metamorphosed Leaves.— This arrangement resembles the distribution of rudimentary leaves over the embryonic stem tip of such a bud as that of *Elodea*. In fact we consider the sepals, petals, stamens and carpels of flowers to be modified or metamorphosed leaves. In some kinds of plants parts can be found intermediate in appearance between leaves and sepals and leaves and petals, and all sorts of gradations are known between petals and stamens. The lower leaves of the garden peony have from nine to eleven leaflets arranged in twos or threes. Nearer the flower the number of leaflets decreases until a whole leaf consists of but one leaflet. This simple leaf with its short, narrow petiole resembles a single leaflet of the compound leaf. Still nearer the flower we find leaves in which the petiole is broadened into a flat scale, while the blade is smaller and smaller until it is merely a small, green, tongue-shaped structure; later still it is a small bristle in the topmost hollow of the scale; and finally it is entirely absent. There remains a thin, yellowish-green scale reddish at the edge. This is a sepal, which is evidently a

modified leaf in which the lamina has never developed and the petiole has been broadened and flattened, the transformation taking place as it were before our eyes. So too we can find in

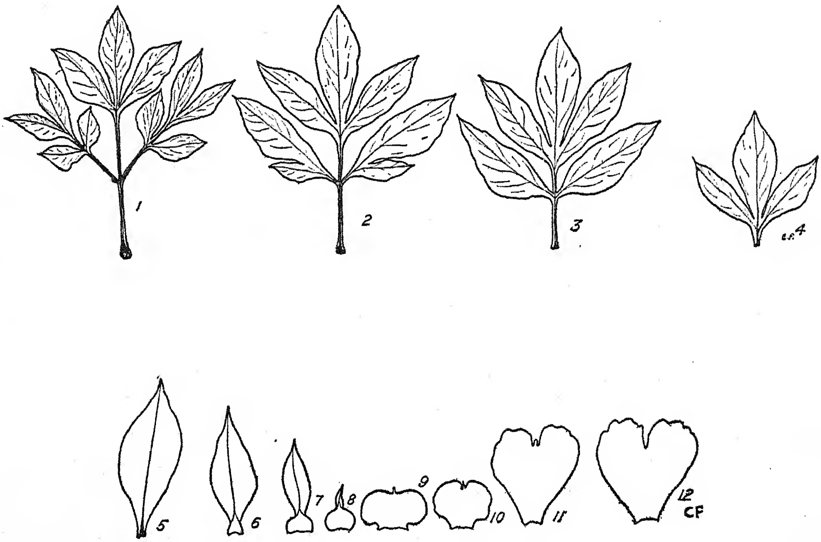


FIG. 303. Leaves, sepals and petals of the peony, illustrating that sepals and petals are modified or metamorphosed leaves. *1*, one of the lower leaves; *2–7*, leaves successively nearer the flower; *8*, *9*, *10*, sepals; *11*, *12*, petals.

flowers transition forms between sepals and petals (in *Camellia*) and between petals and stamens (water lily). In some horticultural varieties some or all of the stamens and carpels remain leaf-like and double flowers of one sort or another result. The attacks of a fungus, *Albugo candida*, which causes white rust on radishes, mustard and related plants, sometimes causes in these hosts the substitution for the stamens of organs partly stamen-like, partly petal-like.

The sepals of the buttercup flower described above, being the outermost part, protect the inner portions, especially while the flower is a bud. The colored petals protect the inner parts and are important also in the attraction of insects which assist in the process of pollination. The stamens and the carpels are the spore-producing organs. Microspores are produced by the stamens which, since they are modified leaves, we may call microsporophylls. The

megaspores are formed by the carpels, which we may call megasporophylls.

215. The Anther and Microspores.—The microspores of a buttercup are found in the anther. Each anther consists of two

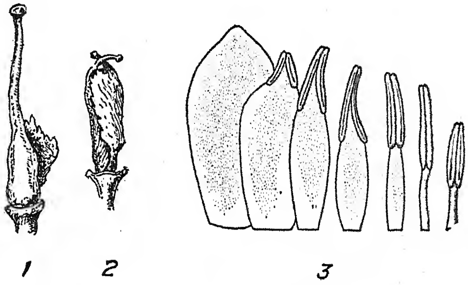


FIG. 304. *1*, *2*, abnormal carpels from cherry flower showing that the carpel is a modified leaf; *3*, a petal (left), a stamen (right) and intermediate forms, showing that a stamen is a modified leaf. (*1* and *2* from Timiriazeff, *The Life of the Plant*, Longmans, Green & Co.; *3* redrawn from Strasburger, Noll, Schenck and Schimper, *Lehrbuch der Botanik*, Gustav Fischer, Jena.)

lobes, and within each lobe are two cavities, four in all. These cavities are the microsporangia and in them are formed the microspores. Each microsporangium is bounded by a wall composed of several layers of cells, which is lined by a single layer of large cells called the *tapetum*. The microspores are formed by the reductional division of spore mother cells, each of which forms four microspores. The development of the spore-bearing tissue of the anther of an Angiosperm is shown by the series of drawings in Figure 305. As the spores are formed and develop the tapetum disappears, its contents being used as food by the growing spores. The contents of the sporangia are freed as follows: certain cells between the two sporangia of one lobe die and wither, so that these two sporangia become united into one cavity. Then certain thick-walled cells in the wall of the anther near the location of the former partition between the two sporangia separate, splitting the whole anther lobe longitudinally and leaving the contents exposed to the outside air.

216. Megasporophylls—Ovules—Megasporangia.—The megasporophylls (carpels or pistils) are the most characteristic and peculiar parts of the Angiosperm flower, the parts which differ-

entiate a flower from a cone. The megaspores are borne, as in the Gymnosperms, in megasporangia, which are found in ovules. But

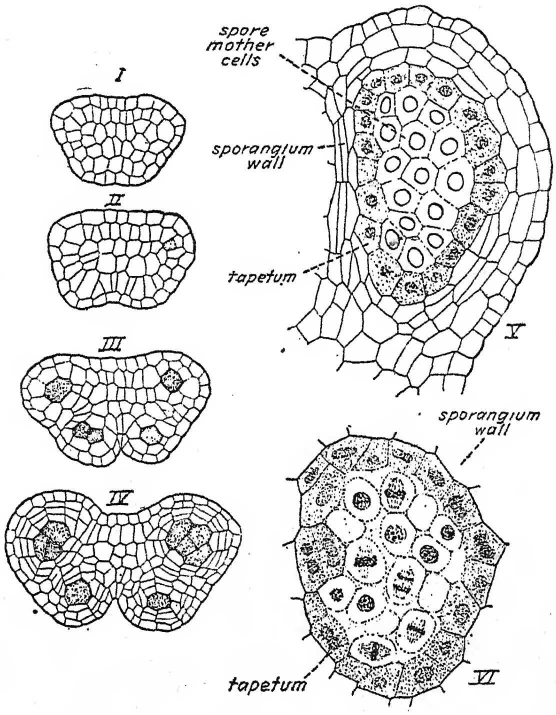


Fig. 305. Cross sections of the anther of *Chrysanthemum* showing stages in its early development. *I–IV*, stages in the differentiation of sporogenous tissue; *V*, a single microsporangium containing microspore mother cells; *VI*, microspore mother cells dividing. (*I–IV* from Warming, *Systematic Botany*, copyright 1895 by The Macmillan Company; reprinted by permission. *V*, *VI* from Bower, *Botany of the Living Plant*, after Figuier, *The Vegetable World*, Hachette et Cie.)

no ovules are visible on the outer surface of the megasporophyll of a buttercup flower. The lower part of the megasporophyll—the ovary—is hollow, and the single ovule is *within* this part. It is this peculiarity in the location of the ovules to which the Angiosperms owe their name. The ovules are *enclosed by the sporophylls* which produce them. They develop into seeds, as do the ovules of a pine. And the seeds also are enclosed by the ovaries, which develop at the same time and become the *fruits*. *Angiosperm*

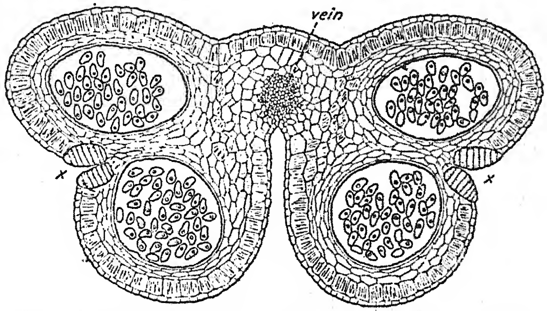


Fig. 306. Cross section of a lily anther showing four microsporangia containing microspores. The cells separating each pair of sporangia later disintegrate and the fused sporangia split open at *x*. (From Bergen and Davis, *Principles of Botany*, Ginn & Co.)

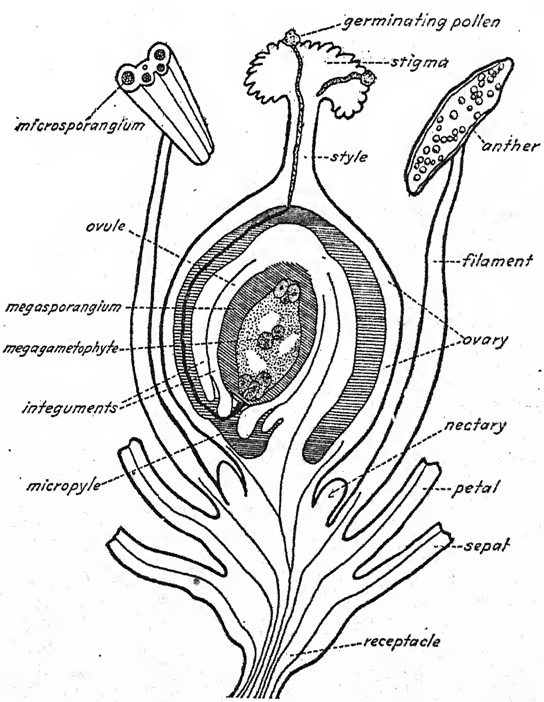


Fig. 307. Diagrammatic lengthwise section of a typical flower. (Redrawn from Sachs.)

means "enclosed seeds." In the pine the ovules are found exposed *on the surface of a megasporophyll;* they develop into seeds which are easily visible on the surface of the enlarged sporophyll. *Gymnosperm* means "naked seeds."

The megasporangia do not differ essentially from those of a pine. Like the latter, each is enclosed by a special covering, the integument. As in the pine the integument does not quite close at one end, but leaves a tiny opening, the micropyle. The megasporangium together with its enveloping integument is the ovule. The ovule is attached to the inner wall of the ovary by a short stalk, the *funiculus*, which is attached to the integument. The part of the ovary to which the ovule is attached is called the *placenta.*

217. Differences among Flowers.—Everyone knows that flowers differ greatly in shape, in size, in color, and in odor. Indeed, it is chiefly by their flowers that we identify the different groups of Angiosperms; for though there are so many kinds of flowers, they are very constant for one plant and its descendants, and hence may be used as a basis of classification.

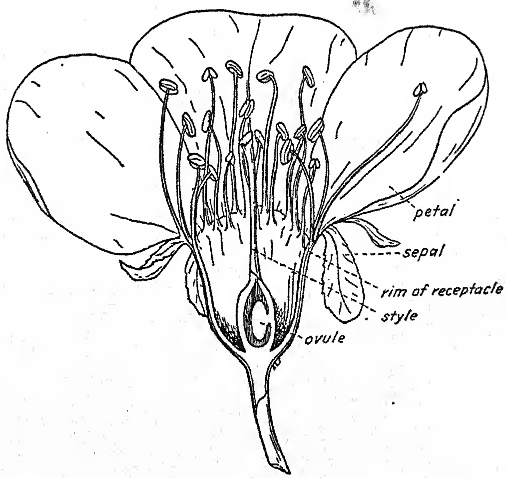


FIG. 308. Sour cherry (*Prunus Cerasus*). Median lengthwise section of flower. (From Robbins, *Botany of Crop Plants*, P. Blakiston's Son & Co.)

If we examine the flower of a cherry, we find that there is but one carpel, in the center of the flower. Its structure is much the same as that of one carpel of the buttercup, except that it contains two ovules. The stamens, sepals, and petals also are quite similar

(except for the white color of the petals) to those of the buttercup; but they do not arise from the portion of the receptacle beneath the carpel. Instead they are found growing from the rim of a cup-like structure which arises on all sides of the carpel. This cup is the enlarged receptacle. The carpel is at its center, the remaining floral parts on its margin.

The lily flower exhibits several features different from those above described. Its floral leaves are all alike in color and texture and size. There are, however, two distinct rings of perianth parts, an outer and an inner; we may call the outer ones sepals and the inner ones petals just as in the buttercup. The receptacle is small,

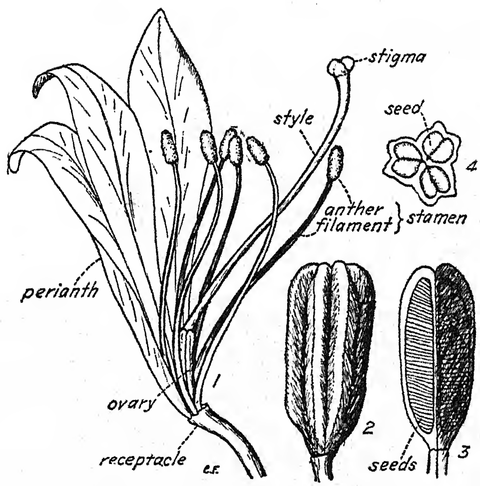


FIG. 309. Lily. *1*, flower with part of perianth removed to show pistil and stamens; *2*, fruit; *3*, lengthwise section of fruit; *4*, cross section of fruit.

a mere knob at the base of the flower, and all the parts are attached very close together. The stamens are not numerous or indefinite in number, as in the flowers previously described, but limited to six. It is in the carpels, however, that we find the most striking difference. There are three carpels, *all united to form one body* in the center of the flower. This body has much the same shape as a single carpel of the cherry or buttercup; a swollen lower portion, the ovary; a slender style; and a terminal stigma. But running lengthwise through the entire structure one may see several lines, some of which represent the lines of junction of the three carpels.

And a section across the ovary reveals three cavities or chambers within the ovary, each containing ovules. The ovules are numerous and are arranged in six vertical rows within the ovary; in one cross section six ovules are to be seen, two in each carpel.

The possession of united carpels is a feature common to many Angiosperms. Externally considered, the structure we find at the center of a lily flower resembles that at the center of a cherry blossom; both have the same general shape and parts, and both contain the ovules. Hence both have been called by the same name, the *pistil.* But one is made up of one carpel, the other of three united carpels; and in other sorts of flowers the pistil may be composed of two, four, ten, or any small number of united carpels. The term pistil refers therefore to the part of a flower which produces the ovules, whether it be a single megasporophyll or several fused to form one structure. In some flowers the carpels are only partially united to form the pistil. The pistil of a maple flower consists of

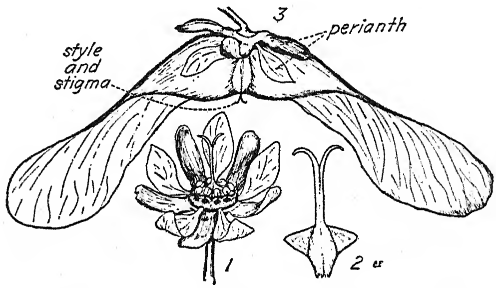


FIG. 310. Maple, *Acer platanoides.* *1*, maple flower; *2*, stage in fruit development showing the wings forming; *3*, mature fruit.

two carpels; the lower parts are united to form one ovary with two cavities; but arising from this ovary are two styles only partly united, each with its stigma. The same situation is found in the apple, which has a compound pistil of five carpels, the ovaries of which are united but the styles and stigmas separate, or nearly so.

Another peculiar feature of many flowers is illustrated by the apple. We have already seen that in such a flower as that of a cherry the receptacle grows out sideways to form a cup, which bears the stamens and perianth on its rim. In the apple the receptacle rises around the ovary of the pistil and *is united with it,*

so that it is difficult to see just where ovary ends and receptacle begins. The inner part of the body thus formed is the ovary and bears the ovules; the outer part is receptacle, and bears the perianth

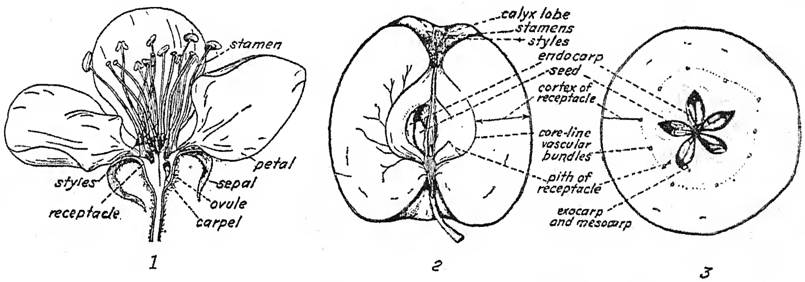


FIG. 311. Apple, *Pyrus Malus.* *1*, median longitudinal section of flower; *2*, median longitudinal section of fruit; *3*, cross section of fruit. (From Robbins, *Botany of Crop Plants*, P. Blakiston's Son & Co.)

and stamens on its rim. The perianth and stamens seem therefore to arise from the top of the ovary, together with the five separate styles and stigmas. Such a type of ovary is known as *inferior;* in the other flowers discussed, in which the sides of the ovary are

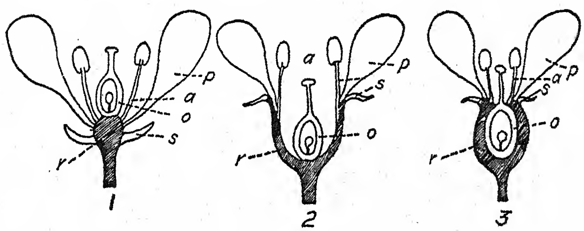


FIG. 312. Diagrams of longitudinal sections of flowers. *1*, *2*, ovary superior; *3*, ovary inferior. *r*, receptacle; *s*, sepal; *p*, petal; *a*, stamen; *o*, ovary. (From Percival, *Agricultural Botany*, Duckworth & Co.)

free—that is, not united with the receptacle—the ovary is called *superior.* Inferior ovaries are found in many familiar plants besides the apple, for instance the pear, banana, currant and gooseberry, narcissus and iris, cucumber, melon, and squash.

The flower of the strawberry presents an interesting combination of the buttercup type of receptacle with the type found in the cherry. The upper part of the receptacle is enlongated and covered with many carpels, each a separate pistil; below this is an expanded

portion shaped like a shallow cup, on the margin of which arise the stamens and perianth leaves. It is the terminal part of the receptacle that afterwards enlarges and becomes the delicious edible part; on its surface the small carpels, each now containing a seed, may still be found.

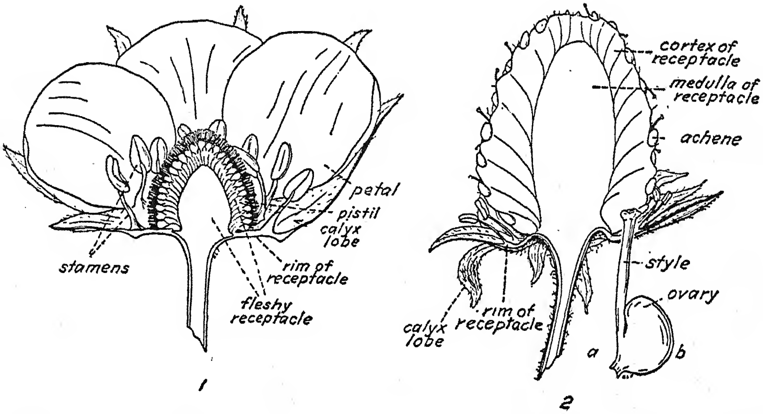


FIG. 313. Strawberry, *Fragaria*. *1*, median longitudinal section of flower; *2a*, longitudinal section of "fruit"; *2b*, a single matured pistil, an achene. (From Robbins, *Botany of Crop Plants*, P. Blakiston's Son & Co.)

The stamens are remarkably uniform in most flowers, though they may differ in the relative size of their parts. Some have long anthers and short filaments, as in the hyacinth, some have long filaments and short anthers, as in the snapdragon; but the structure of these parts remains essentially the same as that already described in the buttercup. The filaments of the hyacinth flower are broad and flat rather than thread-like; and in some plants the filaments of the stamens are united to form a stamen-tube around the carpel or carpels. In the pea nine of the stamens are thus united by their filaments, the tenth one (the uppermost) being free. In some plants, for instance the sunflower, the anthers of the stamens are united, while their filaments are free. The anthers in some kinds of flowers (such as those of the huckleberry) open by terminal holes instead of splitting lengthwise.

The petals are most varied; and of course it is with the great variation of petals in size, shape, number, color, and odor that most of our floriculture is concerned. Without going into endless detail, we may distinguish several general types. A flower of the

buttercup type, in which all the petals are alike, is called *regular*. In the pea there are five petals of three different forms, the uppermost, called the *standard*, being larger than the others and standing erect; the two next below the standard extending laterally and called the *wings;* and the two lower ones united along one edge and forming a boat-shaped body called the *keel*, which encloses the stamens and pistil. Such a flower, in which the petals differ, is spoken of as *irregular*. Frequently more than two of the petals are united. In the snapdragon the petals form one large colored envelope around the sporophylls, and it is only by counting the lobes of this envelope that one can discern that it consists of five petals. The snapdragon flower also is irregular, the two upper lobes differing greatly from the three lower. But some flowers, for instance those of the primrose, have the petals all united and regular.

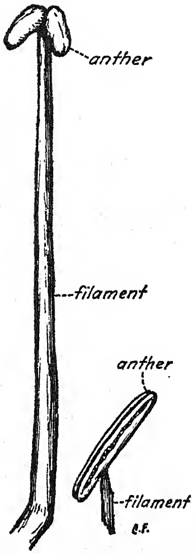


FIG. 314. Left, stamen of snapdragon, *Antirrhinum;* right, stamen of hyacinth.

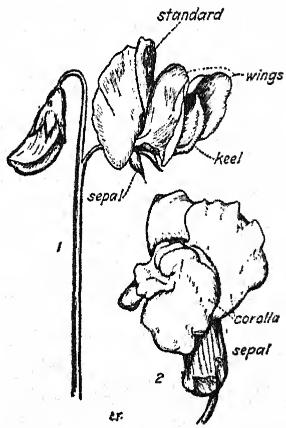


FIG. 315. *1*, Sweet pea, *Lathyrus; 2*, snapdragon.

The sepals are usually green. They enclose the other parts when the flower is yet an immature bud. They are very frequently united, forming a cup (whence the name calyx, which is related to the English word chalice). The perianth consists sometimes of only one ring of leaves; these are then, for the sake of convenience, known as sepals, even if they are colored and shaped as petals usually are. If it seems strange to call the white parts of a buckwheat flower or the purple parts of a clematis flower sepals instead of petals, we must remember that, in flowers which have both petals and sepals, the petals are not always colored nor are the sepals always green. In the larkspur the outer row (sepals) consists

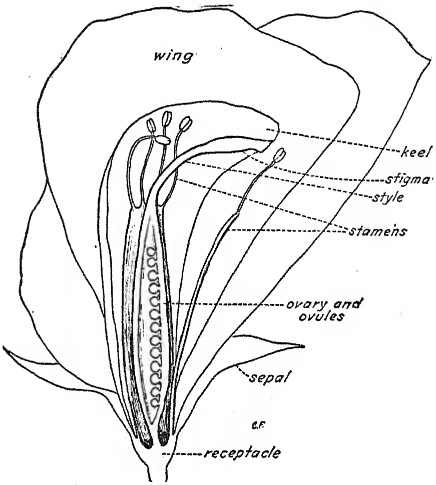


FIG. 316. Sweet pea, *Lathyrus odoratus*. Median longitudinal section of flower.

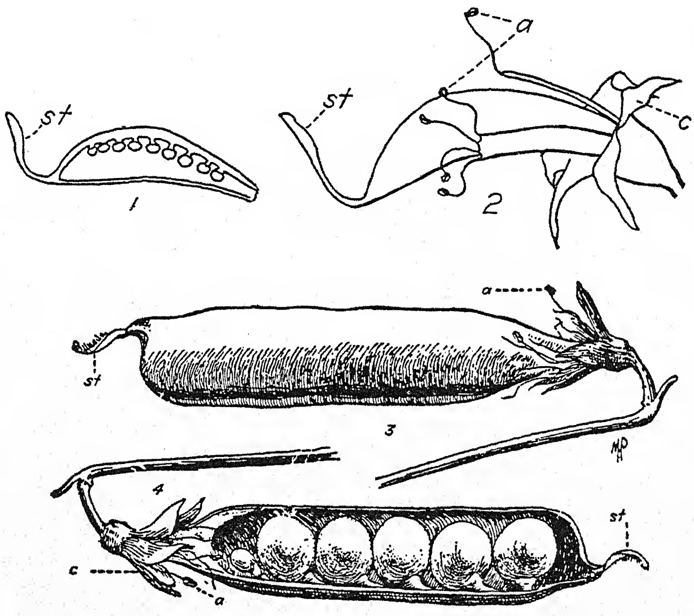


FIG. 317. Fruit of pea. *1*, longitudinal section of pistil showing ovules in ovary; *2*, stage in fruit development; *3*, mature fruit, external view; *4*, longitudinal section of fruit showing seeds. *st*, style and stigma; *c*, calyx; *a*, anther. *1* and *2* highly magnified. (*3* and *4* from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

of brilliant blue parts, while the inner row (petals) is small and greenish. Often there are other leaves connected with the flower and outside the sepals. These are known as *bracts*. In the strawberry flower there is a circle of bracts just outside the ring of sepals, giving the appearance of an extra calyx. In the snapdragon there is a small bract at every point where a flower-stalk arises from the main stem of the plant.

We are so accustomed to valuing a flower by the color and odor of its petals that we are apt to forget that these are the least essential parts as far as reproduction is concerned. Some flowers, for instance those of the cat-tail and of many trees, lack perianths altogether. In many others the sporophylls are surrounded only by small green sepals, as in the common dock and pigweed. Such flowers accomplish their reproductive functions, even though they are less appealing to our eyes. Some common flowers are extremely

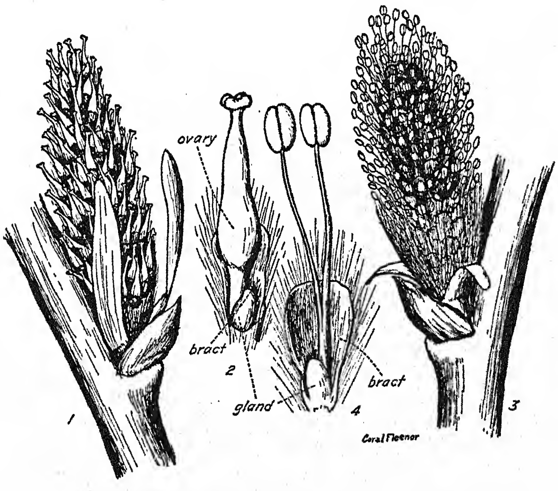


FIG. 318. Flowers of willow, *Salix*. *1*, pistillate catkin; *2*, a single pistillate flower; *3*, staminate catkin; *4*, a single staminate flower.

simple. A single flower of a cat-tail consists of but a single stamen or pistil (both kinds of flower occur on different parts of the same plant), surrounded by a few hairs. The flowers of some species of willows consist either of two stamens and a small scale, or of a single pistil and a small scale; many flowers of one kind are borne by a drooping branch and form what is called a *catkin*. In some

species of willow the young growing catkin is densely covered with long white hairs, attached to the scales of the flowers; hence the "pussy-willows" of earliest spring.

At the opposite extreme to this sort of flower, which consists of little besides sporophylls, are some of those produced in gardens and greenhouses which may consist entirely of perianth. They are consequently of no use to the plant as reproductive structures. Many peonies and geraniums are of this sort.

The carpels and stamens are the *essential* organs of the flower. Many kinds of flowers contain both stamens and pistils and they are called *perfect* flowers. Those of the cat-tail and of the willow are *imperfect*, either staminate or pistillate. When both staminate and pistillate flowers occur on the same plant, as in the cat-tail,

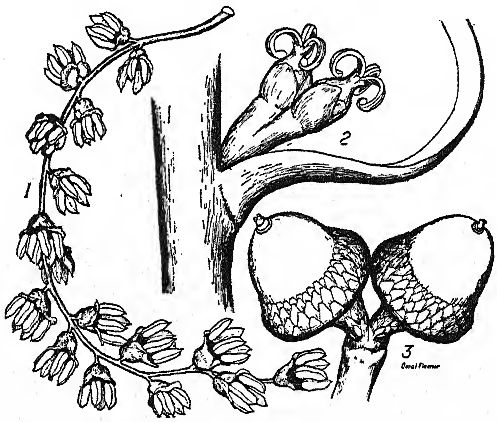


FIG. 319. Oak, *Quercus*. *1*, staminate catkin; *2*, pistillate flowers; *3*, fruits (acorns).

walnut, hickory, oak, and sycamore, the plant is called a *monoecious* plant. When they occur on separate plants, as in the willow and the cotton-wood, the plant is *dioecious*, and only the pistillate plants produce fruits and seed. This dioecious habit is the reason why some cotton-wood trees (the pistillate ones) produce "cotton," which consists of a tuft of long white hairs around the seed, and others (the staminate trees) produce no cotton and are preferred for street planting.

The large and important grass family possesses small flowers of considerable complexity. We do not perhaps commonly think of a grass as a flowering plant. Its flowers are small and greenish.

When they are viewed through a microscope, however, their structures are intricate and beautiful in their delicacy and coloring. Usually many flowers are borne in a long spike or branching cluster.

FIG. 320. A grass, red top (*Agrostis alba*). *A*, panicle of flowers, ½ natural size *B*, single flower, consisting of three stamens and one pistil with two branching feathery styles, all enclosed by scales; ×15.

Each flower consists of a pistil with a two-parted feathery style, the stigmas being the hair-like tips of the many divisions of the styles; and three stamens, commonly so long and slender that they dangle from the flower. It is often the hanging stamens that give a head of grass its feathery appearance. Enclosing these parts

are various greenish scales, often elaborately toothed and ribbed and armed with long bristles. The innermost of these perhaps corresponds to the calyx of ordinary flowers; the others must be called bracts. Indian corn is monoecious, the flowers being of two sorts, either staminate or pistillate. The staminate flowers, each consisting of three stamens (and no pistil) enclosed by scales, are found clustered at the summit of the mature plant, forming the familiar "tassel." Each pistillate flower is composed of a single pistil surrounded by small scales; and a large number of such individual flowers are arranged in more or less regular rows on an enlarged side branch ("cob") and covered with special leaves ("husks")—the whole forming, when mature, the "ear." The brownish "silk" which protrudes from the husks is composed of the tips of the styles and stigmas of all the flowers within the ear. Each ovary finally becomes a grain of corn; the small scales which enclosed the ovary persist on the cob and may be found between our teeth after a dinner including "corn on the cob."

Flowers are used by man for many purposes other than reproduction of the plants. Hundreds of kinds are grown in gardens and greenhouses for ornament; as we have already noticed, these may lack reproductive structures entirely. The cloves of commerce, used as a condiment and as the source of oil of cloves, are the unopened flower-buds of a plant native in the Malay archipelago. Certain flowers (for instance jasmine) are used in the Orient to flavor tea. Many perfumes are distilled from the petals of flowers, although synthetic manufacture has largely replaced the natural source. The petals of some flowers (for instance violets), properly sugared, form a sweetmeat. The common cauliflower is composed largely of a dense mass of flower-buds.

Wonderful as is the variety of flowers, and many as are the uses to which we may put them, it is evident that all flowers (save a few horticultural freaks) are alike in being sporophylls or clusters of sporophylls. In this they resemble the strobili of pines and spruces. The method of reproduction is the same in all—the production of spores by reductional mitosis. And the result of the complete functioning of flowers of any kind is always the formation of seeds, enclosed in fruits. Here again we see, as elsewhere among living organisms, a profusion of variety in structural details, in methods of performing similar functions, all based on a common underlying type.

Gametophytes and Gametes

218. The Gametophytes.—The megagametophyte develops from a megaspore, four of which are formed from the single spore mother cell in the ovule. The spore mother cell contains $2x$

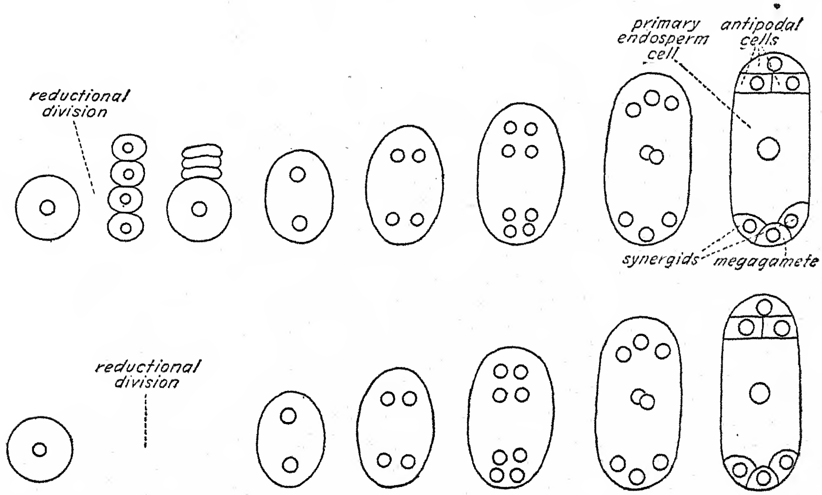


Fig. 321. Diagrams to show the formation of megaspores and megagametophyte. Above, usual method in Angiosperms; below, type found in lily. In each row the spore mother cell is at the left and the mature megagametophyte at the right.

chromosomes, but as the result of reductional divisions each megaspore contains x. Three of these megaspores usually disintegrate and the fourth develops into a megagametophyte by equational divisions. The development of the megagametophyte is short and simple. Its nucleus divides, but no cell wall appears. Each nucleus divides again, and the resulting nuclei yet again, so that there are now eight; all without the appearance of separating walls. Two of these nuclei[1] move to the center of the gametophyte and unite—just as if they were gamete nuclei. The remaining six are arranged in two groups of three each, at either end of the gametophyte. Walls now appear, and the gametophyte becomes a seven-celled structure. Three small cells at the end of the gametophyte farthest from the micropyle are called *antipodal* cells. Of the three at the other end, one is the megagamete and later unites with a microgamete from the pollen tube; the other two are called

[1] Often called "polar nuclei."

synergids. The remaining large cell in the center, containing the nucleus which resulted from the fusion of two nuclei, is called the *primary endosperm cell.* This seven-celled structure is the mature megagametophyte.[2] It is still, of course, enclosed within the

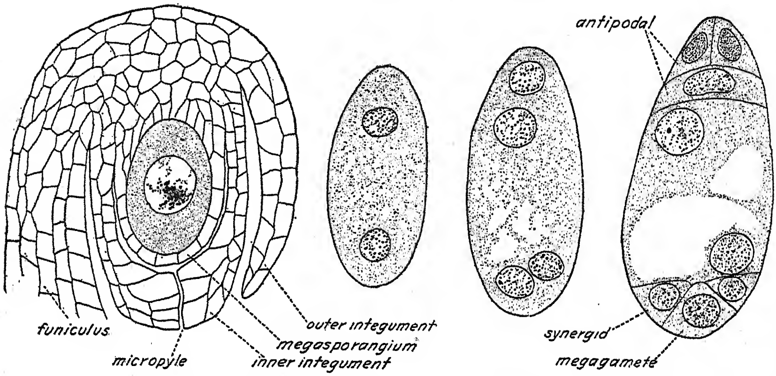


FIG. 322. Development of the megagametophyte in the lily. From left to right, megaspore mother cell within ovule; first division; second division; mature megagametophyte.

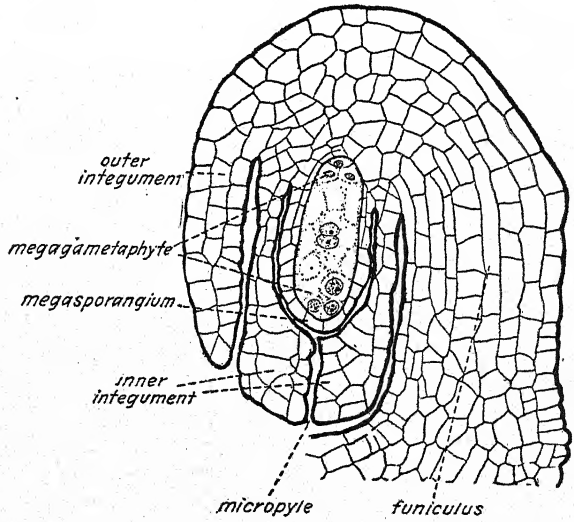


FIG. 323. Megagametophyte in lily ovule as seen in a longitudinal section of the ovule. (Reprinted by permission from *Textbook of General Botany*, by R. M. Holman and W. W. Robbins, published by John Wiley & Sons, Inc.)

[2] Often called the "embryo sac."

megasporangium and integuments of the ovule within the ovary of the pistil, and is entirely parasitic.[3] It is roughly ellipsoidal in shape and about two-tenths of a millimeter in length.

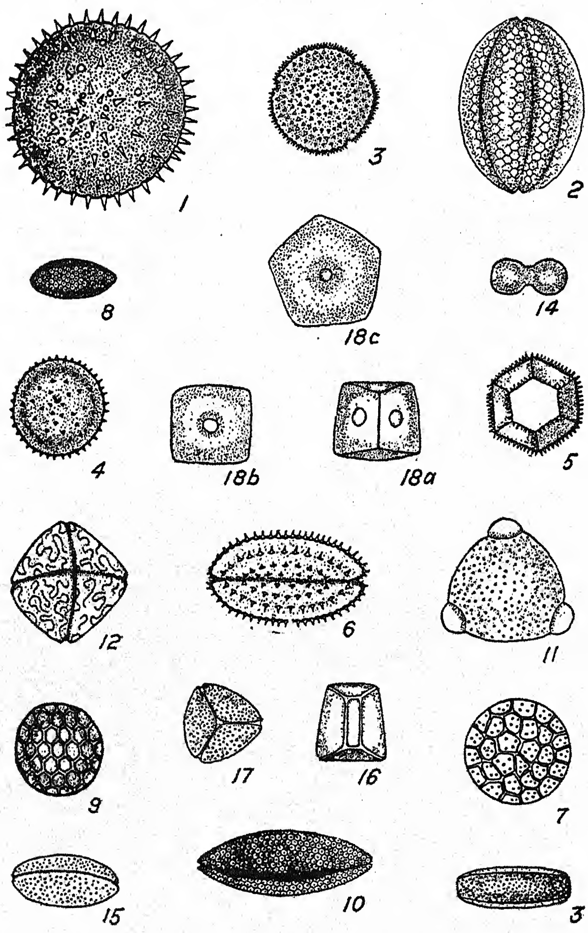


FIG. 324. Pollen grains of various kinds of plants. (From Pope in the Botanical Gazette.)

[3] In the lily and some other monocotyledons an exceptional sort of development takes place. The nucleus of the spore mother cell divides by reductional divisions, but no separating walls are formed; and the entire *four-nucleate body*, which might be considered a four-celled spore, develops into the gametophyte directly, by means of a single additional series of nuclear divisions and the formation of walls. The final result is exactly the same. This sort of a "short-cut" approaches the situation in higher animals, where the reductional division results directly in the formation of the gametes; the haploid generation being limited to the gametes themselves.

In a few Angiosperms the microspores are discharged as such from the anther; but in the majority, just as in the Gymnosperms, the spore first undergoes some development, and becomes a partially developed microgametophyte, before it is discharged. In either case, the spore or young gametophyte is known as a pollen grain. Commonly the pollen grain consists of only two cells: a large cell, occupying most of the grain, called the *tube cell;* and a smaller cell, the *generative cell*, entirely embedded in and surrounded by the tube cell. The wall around the generative cell is very delicate or absent; its nucleus (generative nucleus) is often its only discernible part.

Pollination of Angiosperms consists of the transfer of the pollen to a stigma either of the same flower or of another flower on the

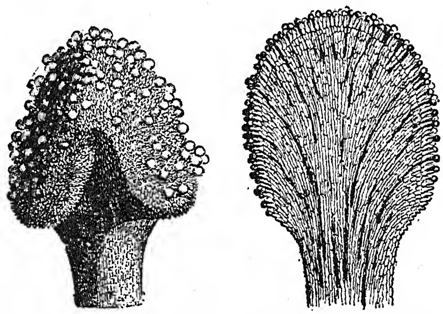


FIG. 325. Left, stigma of jimson weed, *Datura*, covered with pollen; right, longitudinal section of the same showing the pollen tubes. (From Figuier, *The Vegetable World*, Hachette et Cie.)

same or another plant. The stigma is in most kinds of flowers sticky or covered with hairs which catch and hold the pollen. The pollen grains absorb water from the stigma and grow. The pollen grains of many kinds of plants will germinate also in sugar solutions of suitable concentrations. When water is absorbed, the outer layer of the wall of the pollen grain is broken, and the inner layer is pushed out by the enlarging protoplast within. Frequently there are thin places in the wall through which germination takes place. The expanding protoplast of the pollen grain takes the form of a tube—the pollen tube. The protoplast of this tube is the tube cell of the grain; the generative cell floats within it. The tube penetrates the stigma and style of the pistil, growing parasitically at the expense of these parts. Frequently the inner

cells of the style are thin-walled and rich in cytoplasm, and it is from these cells that the pollen tube acquires nourishment. In some kinds of flowers the center of the style is hollow, and the pollen tube follows the wall of this cavity. The pollen tube finally

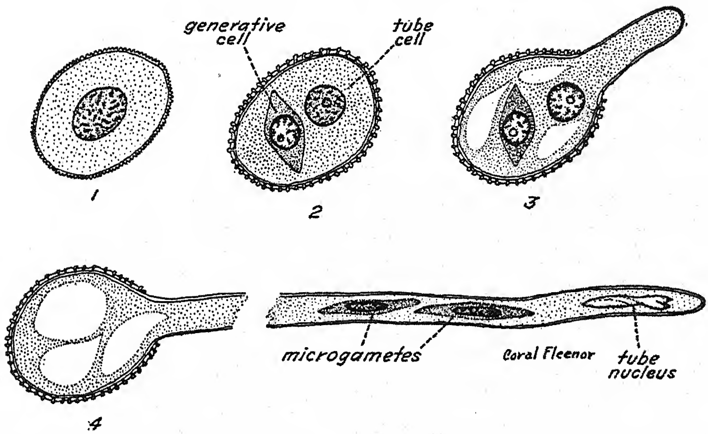


FIG. 326. Stages in the germination of a pollen grain. *1*, microspore; *2*, pollen grain; *3*, pollen grain germinating; *4*, mature microgametophyte; only part of the pollen tube is shown because of its length.

grows into the ovary, where it comes in contact with the ovules; and its tip passes into an ovule, usually through the micropyle, penetrates the megasporangium (nucellus), and so reaches the megagametophyte.

Meanwhile the generative cell, floating within the tube, divides; the two cells that result from this division are the microgametes. The cytoplasm of the microgametes is often not distinguishable from that of the pollen tube by which they are surrounded, their nuclei being their only visible parts. The microgametes, with the nucleus of the tube cell, pass down the pollen tube towards its tip. This movement of the microgametes through the pollen tube is probably caused by the streaming of the protoplasm in the tube, since the microgametes of the Angiosperms have no cilia, flagella or other motor organs.

The pollen grain has now become a *mature microgametophyte*. This consists of the pollen tube, containing the two microgametes, and having the remains of the microspore wall adhering to the upper end. This tiny three-celled plant is a parasite within the tissues of the pistil.

The development of the microgametophyte of an Angiosperm differs from that of a Gymnosperm in this way: the pollen grain of the latter is lodged *within the ovule*, and its tube grows only a short distance before it reaches the megagametophyte inside the megasporangium (a part of the ovule); the pollen grain of an Angiosperm is lodged on the stigma (that is, on the end of the megasporophyll), and its tube grows the length of the style before it reaches even the outside of an ovule, and then bores into the megasporangium. The final destination, of course, is the same in both kinds of plant.

219. Fertilization.—When the end of the pollen tube penetrates the megagametophyte, it breaks, and the tube nucleus, the microgametes, and much of the tube cytoplasm, are discharged into the gametophyte. One microgamete (or at least its nucleus; that is all we can follow) penetrates and unites with the megagamete,

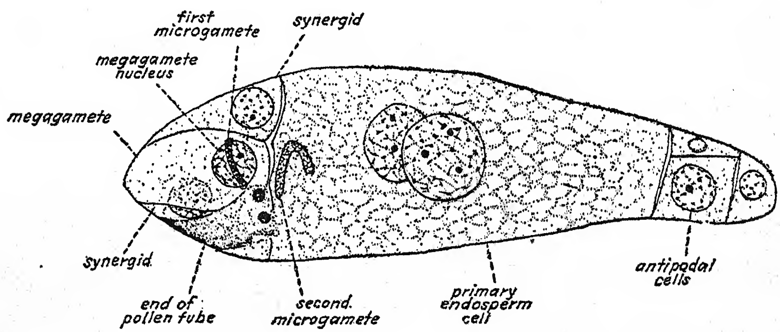


FIG. 327. Fertilization in an Angiosperm. (From Smith, Overton, Gilbert, Denniston, Bryan and Allen, *Textbook of General Botany*, copyright 1924 by The Macmillan Company. Reprinted by permission.)

forming the zygote. The union of the microgamete and megagamete is called syngamy, fertilization or fecundation. The other microgamete nucleus, instead of dying as in a pine, unites with the nucleus (already diploid) of the primary endosperm cell;[4] the latter now has a nucleus whose chromatin content may be symbolized by $3x$. This is the endosperm nucleus. The zygote develops into an embryo sporophyte, the cell containing the endosperm nucleus develops into the endosperm, the entire ovule with its contents into the seed and the pistil into the fruit.

[4] Hence we say that "double fertilization" occurs in the gametophyte of an Angiosperm.

The gametic reproduction of the Angiosperms involves the development of functional megagametophytes and pollen grains, successful pollination, germination of the pollen grain, growth of

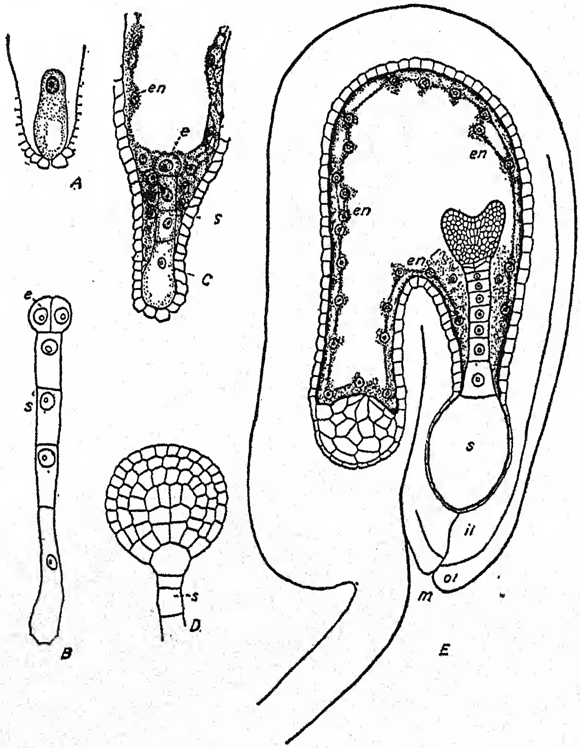


FIG. 328. Stages in the development of the embryo of an Angiosperm. *A*, zygote; *B*, zygote has divided to form a chain of cells, consisting of suspensor (*s*) and embryo cell, itself divided (*e*); *C*, embryo in developing endosperm; *D*, embryo cell (*e*) has formed a spherical mass of cells; *E*, longitudinal section of ovule containing young embryo with cotyledons differentiating. *s*, suspensor; *e*, embryo cell; *en*, endosperm; *m*, micropyle; *ii*, inner integument; *oi*, outer integument. (*A–D*, *Lepidium*; from Curtis, *Nature and Development of Plants*, Henry Holt & Co. *E*, *Capsella*; from Bergen and Davis, *Principles of Botany*, Ginn & Co.)

the pollen tube to the ovule, formation of microgametes, and syngamy, or fertilization. Even after the successful completion of this complicated series of events, the seed, containing an embryo sporophyte and suitable stored food, must develop, be distributed and germinate before the new sporophyte becomes established.

The failure of any one of these steps means the failure of gametic reproduction. Some of the commonest causes of failure are in the process of pollination, in the development of the pollen tube and in fertilization.

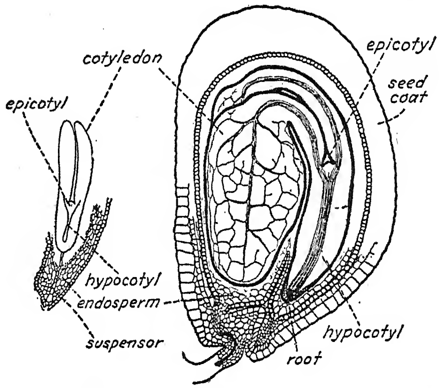


FIG. 329. Later stages in the development of the embryo of an Angiosperm. Left, embryo has differentiated cotyledons, a stem (hypocotyl) partly differentiated into a root tip at one end and an epicotyl at the other; and is surrounded by endosperm. Right, section of ovule in which growth is almost complete and endosperm is nearly exhausted. (From Curtis, *Nature and Development of Plants*, Henry Holt & Co.)

220. Differences in Methods of Pollination.—The pollen may fall on the stigma of the same flower and there continue its development. In many kinds of flowers this takes place before the flower opens, so that the opening of the flower, if it occurs, seems to be

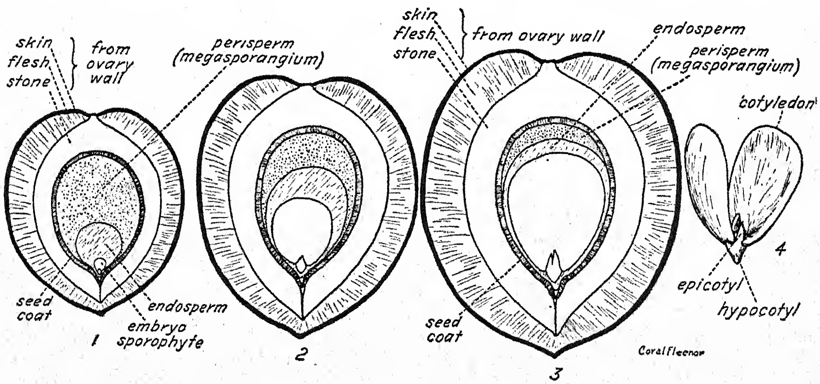


FIG. 330. *1*, *2*, *3*, stages in the development of the fruit of the plum; the fruit is not quite mature in *3*. *4*, the embryo sporophyte removed from the seed.

entirely without benefit to the plant. Some violet flowers are of this type.

On the other hand there are some kinds of plants in which successful fertilization will not occur, seeds will not develop, if the pollen falls on the stigma of the same flower, but will if it is carried by some outside agency to the stigma of another flower of the same kind of plant or a related one. This is true of most kinds of radish.

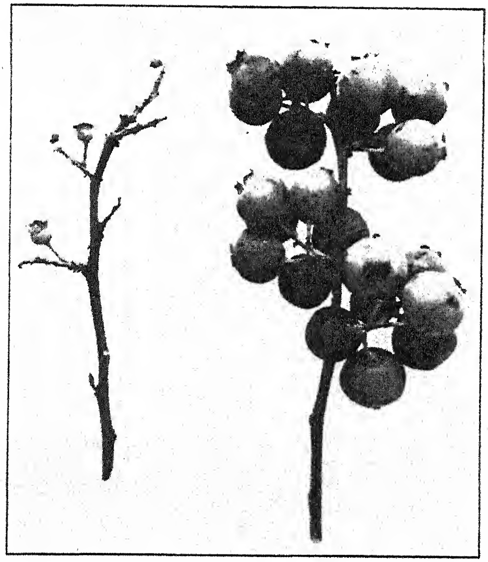


FIG. 331. Effect of self-pollination in the blueberry (*Vaccinium corymbosum*). These two twigs were on the same bush and bore the same number of flowers. The flowers were pollinated by hand at the same time and the twigs were photographed on the same day. The only difference in treatment was that the pollen used on the left-hand twig came from the same bush while that used on the right-hand twig came from another bush. (Courtesy of F. V. Coville.)

The pollen of still other kinds of plants is functional either on the stigma of the flower which forms it or on that of another plant. When the pollen is deposited on the stigma of the flower which produces it, the flower is said to be *self-pollinated.* When it is carried to the stigma of another flower, the process is *cross-pollination.*[5]

[5] These words are used in other senses also, depending upon whether the flower, plant, variety or species is considered a unit. For example some apply the term

Cross-pollination is of great importance in the production of fruit by many kinds of plants of economical importance, for many varieties are *self-sterile* (that is, the pollen will not function on any stigma of the same variety), and the growth of fruits usually depends upon successful pollination. Many important varieties of apples, pears, plums, and grapes are self-sterile, and successful culture of these varieties therefore depends on the transfer of pollen from variety to variety. Even crops which are at least partially *self-fertile* do not produce as abundant or as large fruits when self-pollinated as when cross-pollinated. Blueberries and corn are examples of this. In some important crops, however, such as peas, wheat and tobacco, self-pollination is the normal method and has no ill effects.

The chief methods of pollination among Angiosperms are by wind, by water, and by insects. Any of these may result in either self- or cross-pollination. In self-sterile plants, such as the radish, though both kinds of pollination may occur, only cross-pollination is effective. In dioecious flowers, such as the mulberry, cross-pollination is, of course, the only kind possible. In many kinds of plants, although the pollen can grow on the stigma of the same flower, the arrangement of the flower is such that it is more likely to be carried by insect visitors to some other flower. So that it is a common statement of teleological botanists that "most flowers are constructed as they are in order to ensure cross-pollination."

Many Angiosperms are wind-pollinated, as Gymnosperms are. This is true of many trees, such as oaks and willows. The great grass family is also mostly wind-pollinated. In such plants the stamens are long and slender and dangle in the wind; and the stigmas also are long and feathery and project from the flower. Pollen is produced in enormous quantities and sometimes carried for great distances—most of it, of course, being wasted.

Some plants which grow in the water are water-pollinated. The eel-grass (*Vallisneria*) possesses pistillate flowers on long stalks which reach the surface of the water; and small staminate flowers near the base of the plant. The staminate flowers become detached

self-pollination to the transfer of pollen from one flower to the stigma of another flower *of the same plant*. The same confusion exists in the use of the terms self-sterile and self-fertile. A flower, an individual plant, a variety or a species may be spoken of as self-fertile, depending upon whether or not the pollen is functional upon the stigma of the *flower* which produces it, upon the stigmas of the *plant* which produces it, upon the stigmas of any plants of that *variety*, or of that *species*.

and, buoyed up by gases which they give off, rise to the surface, where they float. They drift upon the surface with their anthers erect, and some of them come in contact with the pistillate flowers, the stigmas of which are long and curved, so that they easily come

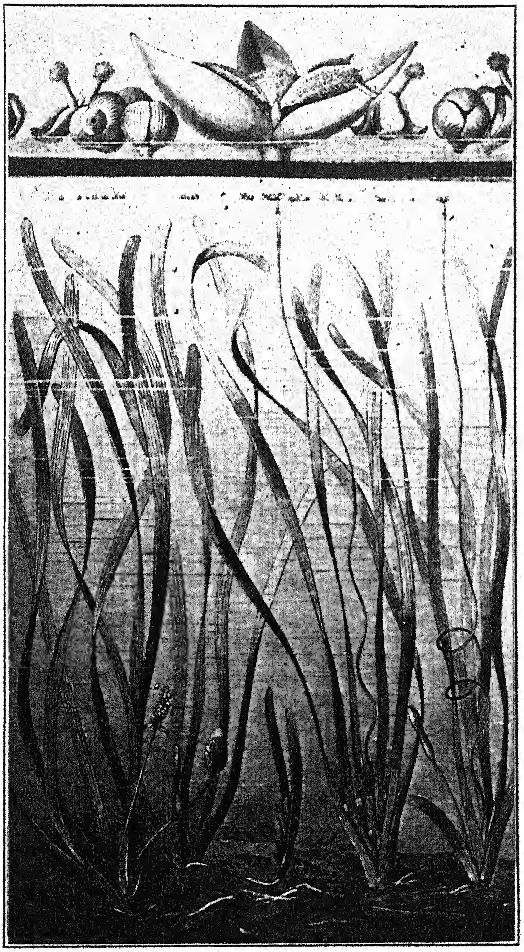


FIG. 332. Pollination by water of eel-grass, *Vallisneria spiralis*. Pistillate flowers float on the surface of water at the ends of long stalks. Staminate flowers break loose and rise to the surface of the water where they open, float against the pistillate flowers, and pollinate them. Entire plants are shown in the lower part of the figure; flowers (on a large scale) floating at the surface appear in the upper part. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

in contact with the anthers bearing the pollen. The surface tension which is created by the slight depression in the surface film of the water around the pistillate flowers facilitates the movement of the staminate flowers toward the pistillate. Other water plants elevate their flowers above the surface, and they are then pollinated by the same methods as are those of land plants.

The majority of flowers are insect-pollinated. The structures of the flowers, described above, which are pollinated by wind or water, are sufficiently remarkable in their adaptation to these methods of pollination. But it is among the insect-pollinated flowers that the variety, intricacy, and delicacy of the numerous arrangements which ensure pollination cause our wonder.

Insect pollination depends largely upon the fact that the petals secrete a substance called *nectar* which is used by the insects as food. The structure of the flower is usually such that the insect, in obtaining the nectar, must brush against stamens and stigma with his body. Pollen grains from many flowers are caught on the insect's body in the course of a day's work and are rubbed off on the stigmas of the same and many other flowers. A good example is provided by the common nasturtium. One of the petals is prolonged backwards into a long hollow spur, in which the nectar collects. To reach this the insect must alight on the broad parts of the petals and thrust its body across stamens and stigma.

Some insects, such as the bees, gather the pollen and use it for their own food and that of their offspring; but in so doing they necessarily accumulate some pollen on their bodies which is rubbed off on some stigma.

It is among the insect-pollinated plants that we find some of the most remarkable arrangements which bring about cross-pollination rather than self-pollination. In some plants, such as the primrose, flowers of two types exist. One has high stamens and a short pistil; the other has low stamens and a long pistil. An insect visiting the first type of flower gets its hind-parts daubed with pollen, while only its fore-parts touch the stigma; when it chances to visit one of the other type, its pollen-covered hind-parts now touch the stigma, while its fore-parts now get covered with pollen. This pollen, again, may be deposited on a stigma of the first type; and so on.

In many flowers, such as the geranium, sunflower, and thistle, the stamens mature before the stigma of the same flower, so that

self-pollination is impossible; when the pollen is being shed, that flower has no stigma mature enough to receive it. At the same time as the pollen is being shed from one flower, however, the stigma of some other, older flower is likely to be mature and receptive, so that, if pollination occurs at all, it will be cross-pollination. In a few flowers, such as the magnolia and the figwort (*Scrophularia*), just the opposite situation exists. The stigma matures before the stamens shed the pollen. The result is just the same.

A remarkable arrangement exists in the sage (*Salvia*). The stamens mature first, and are of a peculiar form (see Fig. 333), such that an insect entering the flower in search of nectar comes in contact with a downward-extending prong, pushes it back, and thereby causes an upper arm, which bears the anther and pollen, to descend and touch it on the back. In other flowers, meanwhile,

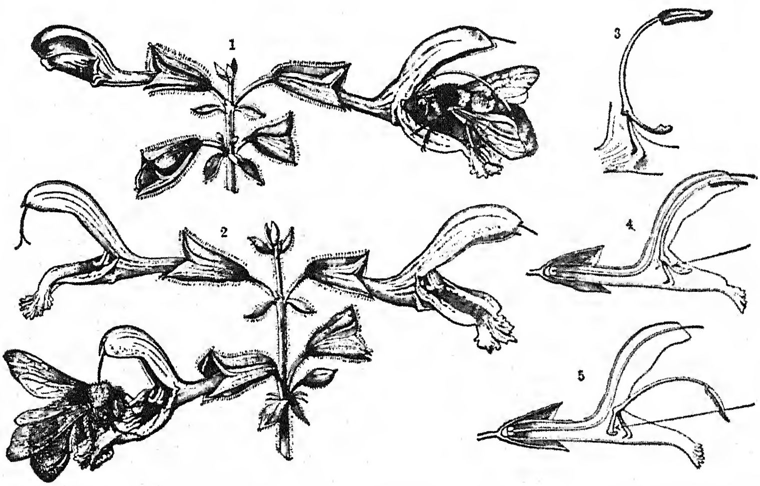


FIG. 333. Pollination by insects of sage, *Salvia glutinosa*. The flower is visited by a bee which pushes the stamen in such a way that its pollen-covered anther strikes the insect on the back (*1*). The anther (*3*) is hinged and has a projecting appendage which the bee touches with its head, thus tilting the anther over (see 4 and *5*). When the bee visits another and older flower (*2*) in which the style and stigma project, cross pollination is effected. (From Kerner, *Natural History of Plants*, Henry Holt & Co.)

the stamens have withered, and the stigma has grown so as to hang down in the mouth of the flower, in such a position that the insect, when it enters the flower, must brush it with its back, and thereby cover it with pollen deposited there by the first flower.

Such a precise and ingenious arrangement excites our wonder; we can forgive the teleologists who, apparently, see in this mechanism evidence of a purpose (cross-pollination) which causes the flower to be so constructed.

221. **Seed Development.**—Just as in a Pine, the integuments become the seed coat; the zygote becomes the embryo; and the megasporangium usually disappears. The new and different feature of the Angiosperm seed is that, instead of the megagametophyte being large and containing stored food, it is small and withers away, *except for one cell*, that which contains the endosperm nucleus; and this, while the zygote is developing into the embryo, grows into a food storage tissue, which (at least at first) surrounds the embryo. This tissue we have already called the *endosperm*. The endosperm is a product of the megagametophyte but not a part of it. It may be considered a separate generation, a separate plant—neither haploid nor diploid, but *triploid*. It is neither sporophyte nor gametophyte, for it bears neither spores nor gametes, and does not reproduce at all. When the seed germinates and the embryo resumes its growth, the endosperm is partly used for food by the embryo sporophyte; the rest withers and dies. Or it may be consumed by the embryo before the seed becomes mature.

222. **The Fruit.**—Essentially, seed development in both Gymnosperms and Angiosperms is the same. The ovule becomes the seed, while still attached to the megasporophyll. But in Gymnosperms the latter is merely a scale, in Angiosperms a hollow container. The ripe seed of a Gymnosperm is found on the surface of a scale, the megasporophyll. The seed of an Angiosperm develops *within* a body formed of one or several megasporophylls, *and as the seed develops a portion of this body, the ovary, develops also.* The ripe seed, therefore, is *enclosed* by the matured ovary; we call the latter (with any other parts of the flower that may remain attached to it) the *fruit*.

The buttercup provides a simple example. Each pistil contains one ovule. As each ovule becomes a seed, each pistil enlarges and becomes a fruit (see Fig. 302). In this plant there is very little difference, except in size, between the pistil and the fruit. The mature fruit of the buttercup is a small pod-like dry structure containing one seed; there are many fruits on one receptacle.

The development of the lily fruit is similar. In the lily, however, there is but one pistil, which is composed of three carpels and

contains many ovules. There is but one fruit (see Fig. 309) from such a flower, containing numerous seeds. As the ovules become seeds, the ovary of the pistil enlarges greatly, the style and stigma wither away. The mature fruit is of the same shape as the ovary of the pistil.

The pistil often changes markedly as it develops. The pistil of a cherry flower changes into the cherry we eat and the stone we throw away—within which is the seed.

Often other parts of the flower are involved in the fruit. The ovary of an apple blossom is inferior—its walls are united with the stem (receptacle) which bears it and surrounds it. As the seeds develop and the ovary enlarges, the surrounding stem tissue also enlarges and becomes fleshy (see Fig. 311); it is the part of the apple that we eat. When we eat an apple, we are really eating an enlarged flower-stem (receptacle); we throw away the fruit proper (ovary), which is contained in the "core."

The growth of the fruit is in most kinds of plants dependent upon pollination and fertilization. If these do not occur, the flower falls and no fruit is formed. In some varieties of grapes, however, fruit is formed without fertilization, if pollination has occurred. Without fertilization the ovules do not develop into seeds, and we have a seedless grape (or raisin). In some other kinds of plants, the fruit develops even without pollination. The best known examples of this are the banana and the navel orange. The tiny brownish specks near the center of the banana fruit are the remains of ovules which failed to develop into seeds.

223. Kinds of Fruits.—Fruits are of immense variety, some edible, some poisonous, many hard and dry. In order to understand the development of the different kinds, it is convenient to classify them.

We may first group them according as they open or not when ripe. If they open they are called *dehiscent;* if not they are *indehiscent.*

The dehiscent fruits are almost all dry fruits and are frequently called pods. Some are composed of only one megasporophyll (carpel). Some of these (for example the fruit of the buttercup) open along one side, and are known as *follicles;* others split along two lines, and are called *legumes.* The pods of peas (Fig. 317) and beans are legumes. The peanut is classed with legumes because of the structure of the flower from which it comes, which resembles

that of a pea or bean; but it is exceptional in that it does not dehisce at all.

Other dehiscent fruits are composed of several carpels; they usually open by as many lines as there are carpels. These are called *capsules*. The fruit of the lily is an example.

The indehiscent fruits may readily be divided into two groups, the *dry* and the *fleshy* fruits. Of the former there are several varieties; an *achene* is a small, dry, indehiscent, one-seeded fruit (for example a buckwheat "seed," which is really a fruit); a *nut* (such as an acorn) is like an achene but with a very heavy and hard outer wall; a *samara* (Fig. 310) is like an achene with part of its wall prolonged into a wing (as in the fruit of maple or ash). The *caryopsis* is like an achene, but the coat of its one seed is united with the fruit wall. It is characteristic of the grasses. A grain of corn or wheat is a caryopsis.

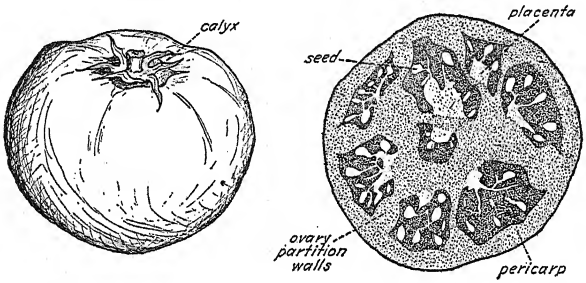


FIG. 334. Mature fruit of tomato, *Lycopersicum*. Left, surface view; right, cross section.

The fleshy fruits include most of our important edible fruits. The simplest type is the *berry*, in which the entire ovary becomes fleshy, as in the grape and the tomato. Some fruits are formed of a fleshy ovary surrounded by a rind which developed from the receptacle. These also are classed as berries, though not popularly considered so—for the banana is one of them. Watermelons, cucumbers, and squashes are of the same general type; but possess certain peculiarities (the toughness of the rind, etc.), which causes us to give them a name to themselves. We call them *gourds* or *pepos*.

When the receptacle surrounding an inferior ovary becomes fleshy, we call the result a *pome*. An example is the apple. This

is just the reverse of many berries. When we eat an apple we eat the "stem" and throw away the ovary; when we eat a banana we peel off and discard the "stem" and eat the ovary.

The ovaries of some plants become partly hard and partly fleshy, the hard part being innermost. Such a fruit is the cherry

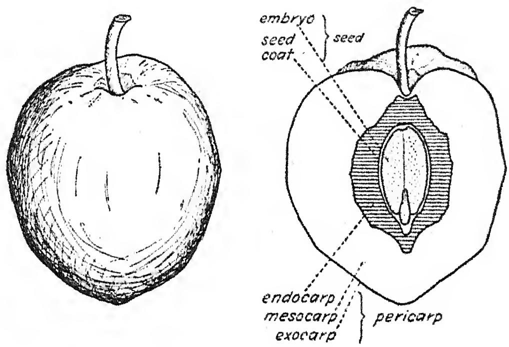


FIG. 335. Mature fruit of plum, *Prunus*. Left, surface view; right, section.

or peach. It is called a *drupe*. The hard stone is often mistakenly called the seed. It is really the hardened inner layers of the ovary, the true seed being inside.[6]

In addition to all these there are bodies popularly known as fruits which are not fruits in the strict sense of the term. A strawberry, for instance, comes under none of the above descriptions, certainly not that of a berry. It is something like a pome turned inside out—an enlarged fleshy receptacle with carpels all over the *outside* instead of being enclosed. The "seeds" that get in our teeth are really individual small fruits of the achene type. A blackberry, again, is formed from a number of separate ovaries on a single receptacle. Here each ovary becomes a tiny drupe—fleshy but with a hard center surrounding a seed. Such "fruits," formed of a number of individual fruits on one receptacle, are known as *aggregate fruits*. Other so-called fruits, for instance the pineapple and mulberry, are formed from many individual flowers (each with its pistil) all clustered tightly together. Such "fruits" are called *multiple fruits*.

[6] The different layers of a fruit are sometimes distinguished by the names *exocarp*, *mesocarp*, and *endocarp*. In the drupe these would be, in order: skin, flesh, and stone.

We find, therefore, that ordinary names of fruits, not being based on detailed study, are misleading; one name (*e.g.*, "berry") may be applied to many different sorts of structures. And, while we try in scientific botany to keep the popular names as much as possible, so as to avoid inventing an entire new set of words, we have to define and restrict these names considerably.

224. **Dispersal of Seeds.**—If a seed of a tree germinates in the soil shaded by the parent tree, its development is often hindered by its own parent. The light is of low intensity, and the room for growth limited. As a matter of fact, the seeds are usually scattered, by various means, so that each kind of plant has a tendency to spread to new regions. In the dispersal of seeds the fruits often play an important part. The fleshy kinds (berries,

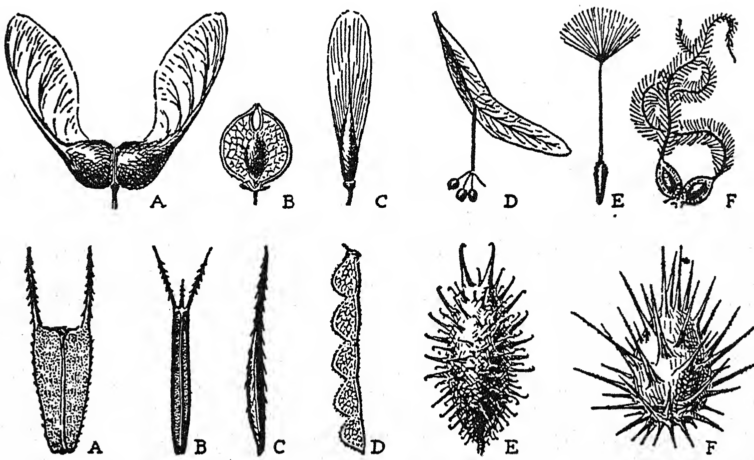


Fig. 336. Types of fruits. Above: *A*, maple, *Acer; B*, elm, *Ulmus; C*, ash, *Fraxinus; D*, basswood, *Tilia; E*, dandelion, *Taraxacum; F*, *Clematis*. Below: *A*, beggar-tick, *Bidens; B*, Spanish needle, *Bidens; C*, sweet cicely, *Osmorhiza; D*, tick trefoil, *Desmodium; E*, cocklebur, *Xanthium; F*, sand-bur, *Solanum*. (From Transeau, *General Botany*. Copyright 1923 by World Book Company, Publishers, Yonkers-on-Hudson, N. Y.)

drupes, etc.) are eaten by birds and other animals and the seeds then carried away and deposited in places perhaps far from the parent plant. The seeds of such fruits usually have a tough seed coat, or are surrounded by a hard layer of the ovary, which protects the embryo and endosperm from digestion by the animal. Some fruits have prickles or hooked hairs which cause them to

become attached to the coats of animals and thus be transported. Familiar examples are "beggar-ticks" and "stick-tights," which often decorate our clothing after an autumn walk through fields or woods. The cocklebur, which is a multiple fruit, has similar properties. Many a "hiker" has been an unconscious agent in the spread of such familiar weeds. Some fruits when touched open violently—explode, as it were—ejecting their seeds with considerable force. The familiar "touch-me-not" (balsam or jewel-weed) derives its name from this property. Some fruits have a thin expanded portion or a tuft of hairs which catches the air and makes it likely that the fruit will be carried away by the wind. Familiar examples are the samaras of maple and ash and the achene of the dandelion. Sometimes, however, the fruit discharges the seeds without falling from the parent plant, and it is the seeds which possess structures making for their dispersal. This is true in the milkweed; the follicles open while still attached to the parent and liberate the seeds, each of which possesses a tuft of long silky hairs which catches the wind.

Whether or not a fruit is transported, by its decay it enriches the soil with inorganic nutrients,[7] which are used by the young plant which develops from the seed. This is particularly true of the fleshy fruits. The possession of fruits therefore is in more ways than one an agent in the perpetuation and extension of a species, and is one of the causes for the great abundance of Angiosperms on the earth to-day.

225. The Life History of an Angiosperm.—The life history of an Angiosperm is a complex affair. No mere diagram can do it justice. It is worth while, therefore, to summarize what we have been describing, as follows:

In the seed is found an embryo sporophyte, with rudimentary stem and root, and cotyledons, and perhaps rudimentary leaves. This, after being dormant in the seed for a short or a long time, resumes growth, using at first food stored in the seed; and becomes a mature plant consisting usually of roots, stems, and leaves.

This plant may reproduce vegetatively, by its roots (sweet potato), stems (grass, strawberry), or leaves (*Bryophyllum*); or by seeds.[8]

[7] See the Chapter on Bacteria.

[8] Reproduction by seeds involves a large part of the life cycle, from a sporophyte through the gametophytes to the new sporophyte. It therefore includes reproduction by spores and by gametes.

Some kinds of plants are annual, forming flowers their first season and then dying. Some are biennial; during the first year they store a large surplus of food, usually in the root (for instance the carrot or parsnip); when winter comes, all parts die except that which contains this food; next spring it develops anew the missing parts, and finally flowers and seeds are formed, and the entire plant dies. Some plants again are perennial; they live from year to year by means of an underground stem, or a bulb, or some similar part, or by a woody stem; each year developing all the other parts, including flowers.

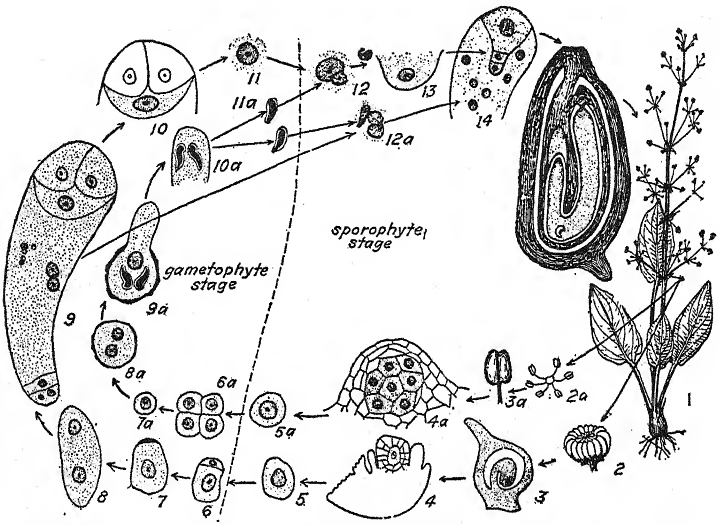


Fig. 337. Diagram of the life-cycle of an Angiosperm. (After Schaffner from Gager, *Fundamentals of Botany*, P. Blakiston's Son & Co.)

The flowers are spore-bearing organs, consisting of sporophylls which produce two kinds of spores in sporangia. The spores are formed by reductional division and therefore give rise to a haploid generation—the gametophytes.

The haploid generation is small and parasitic upon the diploid. The microgametophyte develops partly within the microsporangium, is transferred to the pistil (pollination) and there completes its development, and forms microgametes. Meanwhile the megagametophyte develops (from a megaspore) and forms a megagamete within the ovule. The pollen tube of the microgametophyte

reaches the megagametophyte, and union takes place of one microgamete (from the pollen tube) with the megagamete. At the same time a second "fertilization" occurs, the union of a second microgamete with the primary endosperm nucleus of the megagametophyte.

The zygote formed by the union of the gametes becomes an embryo sporophyte. The cell containing the endosperm nucleus becomes a many-celled endosperm surrounding (at least for a time) the embryo. The integument of the ovule becomes the seed coat. The whole structure is a seed.

Meanwhile the ovary containing the developing ovule also develops, and becomes the fruit. The nature of the fruit varies much with the kind of plant. Finally it is eaten, or decays, or dries and splits open, and the seed may be deposited on the ground. After a period of dormancy (usually over winter) the seed germinates, and the cycle begins again.

CHAPTER XXV

INHERITANCE

We have been discussing fruits, seeds, flowers, leaves and stems. We have seen what a remarkable variety of different forms, colors, sizes, and functions these parts have in different kinds of plants. It is no less remarkable that the forms and functions which these parts assume in any particular race of plants (that is, plants related to each other by descent) are fairly uniform. If an apple tree reproduces vegetatively or by seeds, the offspring[1] and its offspring and the whole line of descent are apple trees, not rose or strawberry plants, not even pear or quince trees. So it is with other kinds of plants (and animals). Each through reproduction maintains its own kind generation after generation. We assume that this is because the new individual is at first, when one or a few cells, an isolated bit of the protoplasm of the parent or parents which has, so to speak, "set up for itself" in the world. And it is reasonable to suppose that this protoplasm, when it grows, should grow in the same way, and result in the same sort of product as did the parental protoplasm when *it* grew—being just another sample of the same stuff. It is not difficult then for anyone who is acquainted with the fundamental facts of reproduction to understand why offspring should come true to type. They do so because of their biological inheritance, their protoplasm which came from their parents in reproduction.

Neither is it difficult to understand why under some circumstances offspring should differ from their parents. It is obvious that a sufficient dissimilarity in the environments in which parents and offspring develop might produce differences between them. If the parent or parents grew with sufficient light in rich, well-watered soil and the offspring grew with deficient light in infertile, poorly watered soil, the latter might be expected to differ in some respects from the former.

Then again in gametic reproduction the new individual originates

[1] The terms parent and offspring are used here in the sense of successive diploid individuals, omitting the microscopic haploid individuals.

from protoplasm derived from two parents—though joined into one unit, the zygote. If these two parents differ—as they may—the resulting mixed protoplasm might be expected to develop into an individual different in some respects from the parents. The biologic inheritance of an organism as well as the environment in which it develops may account for the differences between it and its parents.

While it is easy to understand in this general way that the biologic inheritance of offspring may cause them to resemble and yet differ from their parents, it is more difficult to predict what those resemblances and differences will be. Suppose that the pollen from a red sweet pea reaches the stigma of a white sweet pea and germinates there and gametic union occurs. When the resulting mixed protoplasm again develops into flowers, will they be white or red or pink or of some other color?

The question has more than a theoretical importance. Suppose we have two cherry trees of which one is hardy but yields small, sour fruit, the other has large and sweet cherries but is not hardy. If we "cross" the two, will we get a kind of cherry which unites all the good qualities? Or all the bad ones? Or what? Of course there is one way to find out; to try it. And man has been trying it for hundreds of years. This is called experimental breeding. Part of the results are preserved in the cultivated plants that grow in our gardens, orchards and fields and in the domesticated animals which are raised for use or sport; part of them are recorded in papers and books where the details of the experiments attempted, the results secured, the generalities made and the explanations for those results are given. The scientific knowledge of the results (frequently expressed in brief summaries called laws) and the explanations for them comprise the science of Genetics. The science of Genetics is primarily concerned with the results of inheritance and its mechanism.

The *result* of the biologic inheritance [2] of an organism is the

[2] The word Heredity is commonly defined as "the transmission of characters from parents to offspring," the physical basis for which is the biologic inheritance. Since as a rule characters are not transmitted, but only protoplasm with the potentiality of developing characters, this common definition of the term heredity is confusing to say the least. The derivation of the word and its use in such expressions as "the individual is the result of his heredity and environment" indicate that, if used at all, it should be synonymous with biologic inheritance. To make the discussion clear and unequivocal the authors have used the longer and more awkward term biologic inheritance, regarding the meaning of which there should be no misunderstanding.

individual, shaped and modified as it may be by the environment in which it develops. The *mechanism* of inheritance, as conceived scientifically at present, involves the observable facts of cell division and reproduction and certain assumptions which will be stated in the discussion which follows.

The results of inheritance in the Spermatophytes may be classified according to the types of reproduction: (1) those resulting from vegetative reproduction; (2) those resulting from reproduction by seeds, which involves reproduction by spores and by gametes. The discussion will be limited to the Spermatophytes because of their economic importance and because most of the experiments on inheritance in plants have been performed with them. Reproduction by spores alone or by gametes alone in the Thallophytes, Bryophytes and Pteridophytes will not be discussed here. Both of these involve the same principles as those illustrated by the seed plants.

The Results of Inheritance

226. Vegetative Reproduction.—Experience has demonstrated that with occasional exceptions vegetative reproduction results in individuals like one another and like the parent. If a twig from a navel orange is grafted upon the root system of a sour orange tree, the branches which develop from the scion bear navel oranges and no other kind. A twig from a Baldwin apple rooted and grown to maturity produces Baldwin apples, though it is impossible to predict what sort of apples will be borne by the trees grown from Baldwin apple seeds. This is a well-recognized horticultural principle which has been demonstrated hundreds of thousands of times. A gardener who wishes to propagate a particularly desirable variety of plants does so by slips, leaf cuttings, by budding or grafting or some other sort of vegetative reproduction, if the plant can be reproduced vegetatively. Occasionally a shoot or a branch distinctly different from the rest appears upon a plant. Vegetatively propagated offspring from this shoot resemble it and not the rest of the plant. These are called *bud sports*.[3] The Boston fern and its forty or more varieties originated as bud sports from a wild tropical fern. The California navel orange is said to have originated as a bud sport on an orange tree in Bahia, Brazil, and all the navel orange trees in California have been

[3] Also called somatic, vegetative or bud mutations.

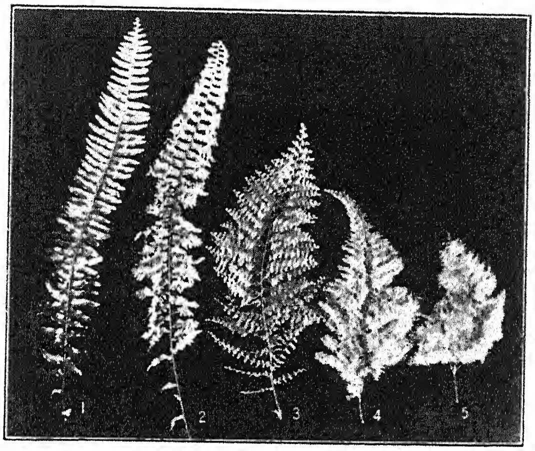


Fig. 338. Mutations of the Boston fern (so-called saltations). The leaf at the left is the normal type, the others are mutants. (From R. C. Benedict in the Bulletin of the Torrey Botanical Club.)

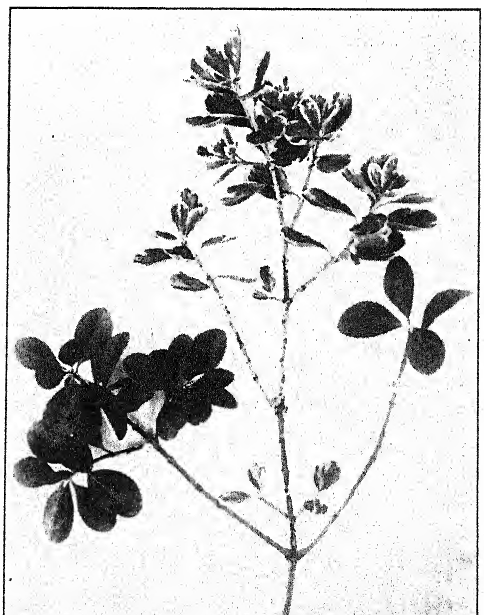


Fig. 339. Bud variation in a limb of *Euonymus*, showing normal and variegated branches. (From Shamel in the Journal of Heredity.)

propagated vegetatively from this bud sport and its descendants. Bud sports are in one respect[4] exceptions to the general rule in vegetative propagation.

227. Reproduction by Seeds.—The experiments which have been performed in breeding plants have shown that some plants breed true and others do not.

228. Plants That Breed True.—Those plants which are in nature self-pollinated, for example peas and beans, usually breed true.

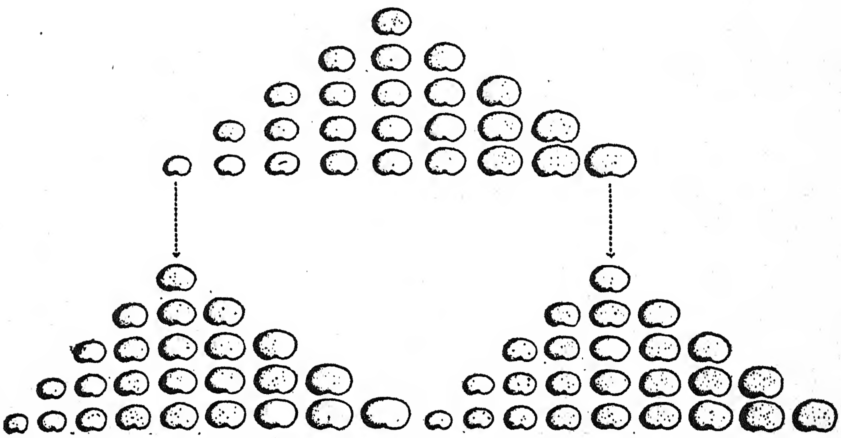


FIG. 340. Diagram to illustrate the results of Johannsen's experiment. (After Baur from Sinnott and Dunn, *Principles of Genetics*, McGraw Hill Book Co., Inc., New York, N. Y.)

Each variety of peas and beans forms seeds which produce plants all alike and like the parents. A variety of peas which is tall and has yellow wrinkled seeds produces more plants (the environment remaining constant) of the same kind and not dwarf plants with green smooth seeds. Small differences in the offspring do occur. Some of the offspring may be a little larger than others and perhaps larger than the parents; some may have seeds a little more wrinkled or a little yellower than others. But these characters are not permanent race differences—they do not necessarily appear in the descendants of the individual possessing them. They are called *fortuitous variations* and are probably due to differences in the

[4] Because vegetatively propagated offspring of bud sports are not like the parent plant. On the other hand they are like the part from which they originate. This part might be considered the immediate parent.

environment which occur even where external conditions are maintained as uniform as possible.

This is illustrated by the experiments of Johannsen with brown Princess beans. He planted a single bean seed and weighed each

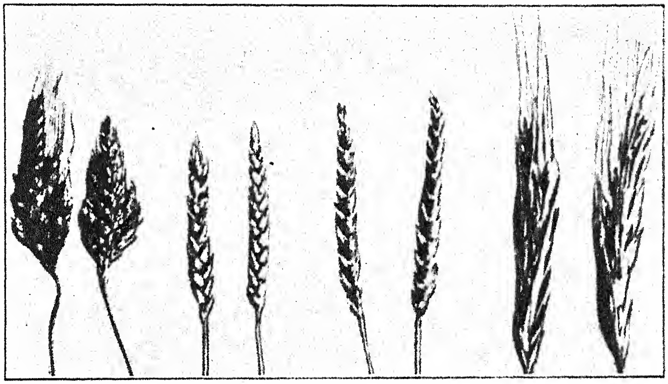


FIG. 341. Four pure lines of wheat which have been grown by Vilmorin for 50 years. The original specimen in the seed museum is shown on the left in each pair. The close similarity of the heads of each pair indicates that pure lines may remain constant indefinitely. (After Hagedoorn from Babcock and Clausen, *Genetics in Relation to Agriculture*, McGraw Hill Book Co., Inc., New York, N. Y.)

of the seeds formed by the plant which grew. Some were heavier than others. He planted the heaviest and the lightest and weighed the seeds formed by each of the plants produced. From the seeds which were formed by the plant grown from the heaviest seed he selected and planted the heaviest seed. From the seeds which were formed by the plant grown from the lightest seed he selected and planted the lightest seed. This he continued to do for six years and at the end of that time the average weight of those seeds produced by the plant grown from the light seed was the same as that of those produced by the plant grown from the heavy seed. This was repeated with the offspring of nineteen beans with similar results. Johannsen called the descendants of a single individual propagating exclusively by self-fertilization a *pure line*. Selection of different-appearing members of one pure line for parents of future generations evidently has no effect on the characters of the race; the biologic inheritance of all is the same.

229. Plants That Do Not Breed True.—The above account shows that plants which are in nature self-pollinated may breed true.

We may add that plants which breed true when self-pollinated and are identical in one or more characters breed true for those characters when they are crossed. But experiment has shown that if two plants differing in one or more characters are crossed the offspring are not true to both parental types and may not be true to either. Furthermore some plants even when self-pollinated do not breed true; this is usually traceable to a cross in their ancestry. The truth of these statements is illustrated by such a well-known

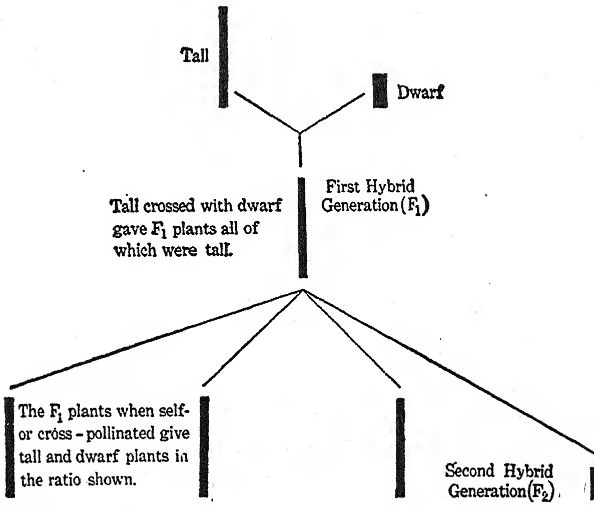


FIG. 342. Diagram to illustrate the results of Mendel's experiment with tall and dwarf pea plants.

example as the failure of an apple seed to reproduce the parental variety. It may be specifically illustrated also by a simple experiment reported by Gregor Mendel in 1865 after eight years of work. Mendel selected peas as his experimental material because the varieties possess constant differentiating characters, because the pea is normally self-pollinated and because crosses between varieties are fertile. He secured from seedsmen thirty-four more or less distinct varieties of peas and in the next two years found that each variety bred true. He selected from this group a variety which was tall (6 to 7 feet) and one which was dwarf (¾ to 1½ feet) and crossed them. Before the flowers matured he opened them, removed the anthers from the flowers of one parent (why?) and

transferred by hand to the stigma pollen from the other parent. All the progeny were tall plants; the dwarf character was not evident. Mendel therefore called tallness *dominant* and dwarfness *recessive*.[7] These hybrids (F_1 or first filial generation) when self-pollinated did not breed true. Their offspring (F_2 generation) numbered 1,064 of which 787 were tall and 277 dwarf. The proportion of tall to dwarf was 2.84 to 1 or in whole numbers 3 to 1.

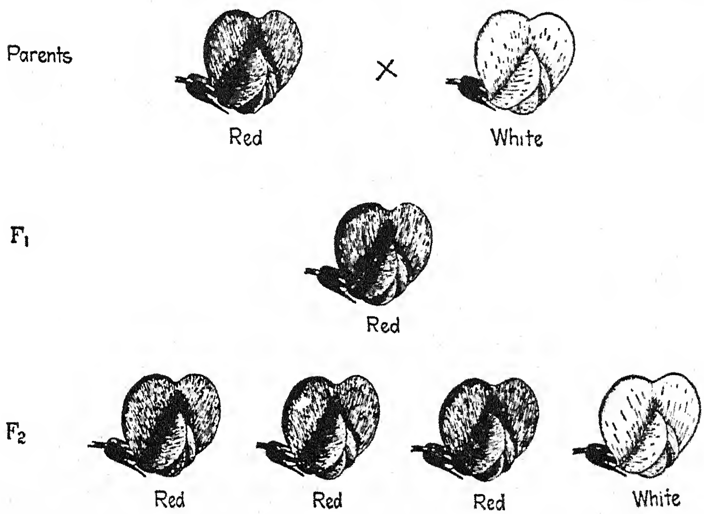


FIG. 343. Cross between a red-flowered and white-flowered sweet pea, both of which breed true when self-pollinated. Red color is dominant. When the hybrid is self-pollinated three-fourths of the progeny (F_2) are red-flowered and one-fourth white-flowered. (From Sinnott and Dunn, *Principles of Genetics*, McGraw Hill Book Co., Inc., New York, N. Y.)

Many other similar results have been obtained: smooth (round) cotyledons are dominant over wrinkled (angular) cotyledons, yellow cotyledons over green ones; black hair in animals is usually dominant over white hair, and so on. Experiments with hundreds of plants

[7] Other pairs of characters with which Mendel worked were the following; the dominant character is given first.

Yellow cotyledons—green cotyledons.
Colored seed coat—white seed coat.
Inflated seed pod—seed pod constricted between seeds.
Green seed pods—yellow seed pods.
Axial flowers—terminal flowers.
Smooth (round) seeds—wrinkled (angular) seeds.

and animals and with thousands of characters have shown, however, that dominance of some characters is only partial, so that the hybrid may develop a character different from those of either

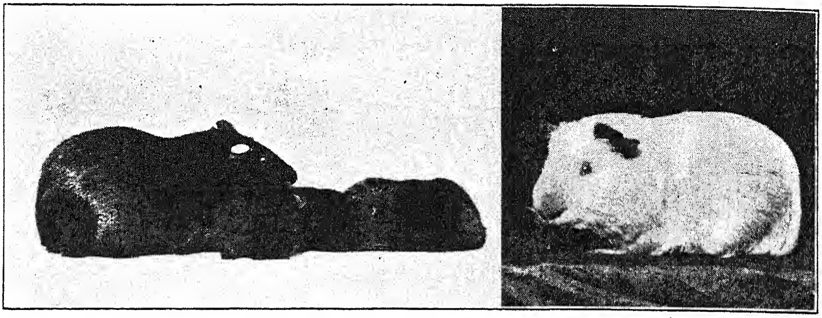


FIG. 344. An example of the results of crossing a pure-breeding black guinea pig and a pure breeding white guinea pig. (From Castle, *Genetics and Eugenics* Harvard University Press.)

parent. A cross of a white-flowered snapdragon with a red-flowered form yields a hybrid with pink flowers.

The Mechanism of Inheritance

In explaining the mechanism, as we know it at the present time, for the above results, we must distinguish between the mature individual and the protoplasmic basis which with the environment caused its development.

An organism is described in terms of *characters*, which are the means by which one individual can be distinguished from another; these include all conceivable items such as leaf shape; flower color; number, arrangement and symmetry of parts; size; chemical composition; length of life; resistance to disease; and so on. The protoplasm from which such a complex organism develops is itself complex, organized into various parts. Some of these parts seem more important than others in development. We *assume* that there are in the protoplasm inherited by an organism bits of material called *genes*[5] which are concerned with the development of particular characters. Thus it is assumed that in the zygote from which a mature rose plant grows there are genes which determine that it will have thorns, genes that determine that the flowers

[5] Also called *determiners* and *factors*.

will be red, genes that determine that it will produce in the flower chemical substances of a pleasant odor, and so on. The genes alone do not insure the development of a particular character, for they coöperate with the rest of the cell (the cytoplasm) and with the environment in any development which may take place.

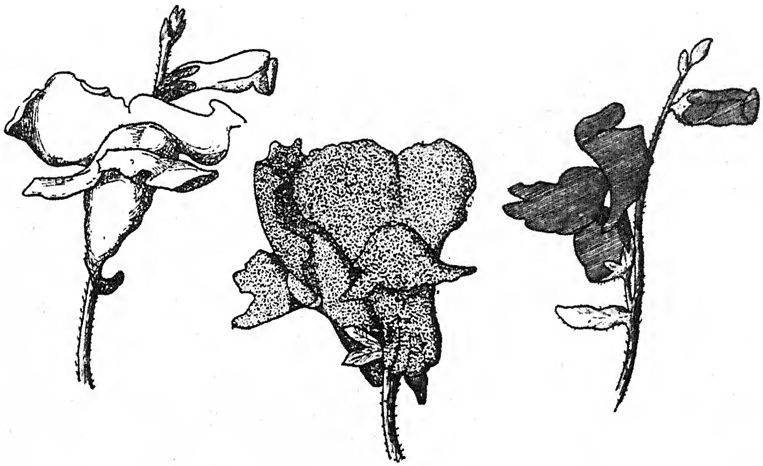


FIG. 345. Partial dominance. The result of crossing a pure-breeding red-flowered snapdragon and a pure-breeding white-flowered snapdragon is a pink-flowered hybrid.

The characters are merely the expression of the possibilities of development determined by the genes. Without certain genes, a particular character could never develop. In the absence of genes for chlorophyll development no possible environmental condition would cause the rose plant to develop chlorophyll. On the other hand, even when the genes are present, no chlorophyll can develop in the absence of certain cytoplasmic bodies (the rudiments of chloroplasts) and light.

It is assumed also that the genes are located in or on the chromosomes in a linear arrangement. We may imagine, for the sake of concreteness, each chromosome as a bead necklace in which the beads represent genes.

230. Vegetative Reproduction.—In equational division, which occurs during growth and vegetative reproduction, the chromosomes are observed to split longitudinally and half of each chromosome goes to each daughter cell, which should therefore receive a piece

of every gene in the original mother cell, if the genes are arranged, as we assume, like beads in a necklace. Since the mature individual develops from the zygote by equational divisions only, every cell of this individual should have the same number and kinds of genes

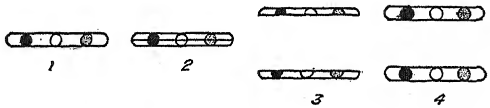


FIG. 346. Diagrams to show the effect of equational division on genes. *1*, chromosome, three genes shown; *2*, longitudinal splitting of chromosome splits genes also; *3*, half-chromosomes and genes separate; *4*, chromosomes and genes grow to full size.

as were present in the zygote; and every cell of any new plant reproduced vegetatively from such a mature individual should also contain the same number and kinds of genes.

It might be expected, however, that occasionally in the innumerable times that equational division occurs in the development of the average mature seed plant (sporophyte) it might not proceed perfectly; an unequal distribution of genes might occur or a gene or some other substance in the cell involved in development of characters might be modified in some way, and a bud sport result.

Our experience with the results of vegetative reproduction may be summarized in a genetical law: Vegetatively propagated plants, the environment being constant and bud sports not occurring, are like one another and like the parent.[6] The mechanism involved is the assumed occurrence of genes linearly arranged in the chromosomes and their equal distribution to daughter cells in equational divisions.

231. **Reproduction by Seeds.**—The mechanism of inheritance in reproduction by seeds includes the same assumptions regarding genes and their location in the cell as presented for vegetative reproduction. It involves also the formation of spores by *reductional division*, the growth from these spores by equational division of gametophytes and finally gametes, and *the union of the gametes* so formed.

We have already learned that the zygote contains a double

[6] Unexplained exceptions to this law have been described. In some kinds of plants a piece of a gametophyte produces vegetatively a sporophyte, not the gametophyte we would expect; or a piece of the sporophyte grows into a gametophyte.

(diploid) number of chromosomes because it originates from the union of two gametes, each of which had the single (haploid) number. These two gametes, being usually of the same species, may contain corresponding and like sets of chromosomes and genes. The zygote which is formed by their union will therefore have *two sets* of chromosomes, each set the duplicate of the other; and for every gene on every chromosome there may be a like gene on a like chromosome in the same cell. This is true also of every cell of the diploid individual—the sporophyte—which develops, by equational divisions, from the zygote.

Diploid plants in which the members of each pair of chromosomes are identical in the genes which they contain are called *homozygous*. Experience has shown that this is an ideal condition rarely found. Very few plants are homozygous for all genes. More frequently they are homozygous for some genes and not for others. As a rule we concern ourselves with only one or a few characters at a time in considering the inheritance of a plant or animal; otherwise the enumeration and study of the characters of a single individual become so difficult as to be impracticable. So for instance we frequently speak of a plant as "homozygous for tallness," which means that in every one of its cells there are two identical genes for the tall character, located in the two members of one of the pairs of chromosomes. The plant may be homozygous or not for the balance of the genes.

Quite commonly some or all of the pairs of chromosomes of a diploid individual consist of chromosomes *not* identical for all genes. In one chromosome, for instance, there may be a gene for tallness; while in the other chromosome of that pair this gene may be lacking and in its place a gene for dwarfness may exist. The individual is then said to be *heterozygous* for this pair of genes. It may be homozygous or heterozygous for the other pairs of genes.

We are now in a position to inquire what is the result in inheritance of the reductional division and of the union of gametes, both of which occur during reproduction by seeds. The existence of pairs of like chromosomes has been demonstrated by microscopic examination. The same sort of evidence indicates that these twin chromosomes are those which pair in reductional division; and during this division the two members of a pair separate and become parts of different daughter cells. If, for example, the diploid individual contains in each of its cells three pairs of chromosomes,

each daughter cell formed by the reductional division will have three chromosomes, one of each of these three pairs. The same is true of the spores, of every cell of the gametophyte, and of the

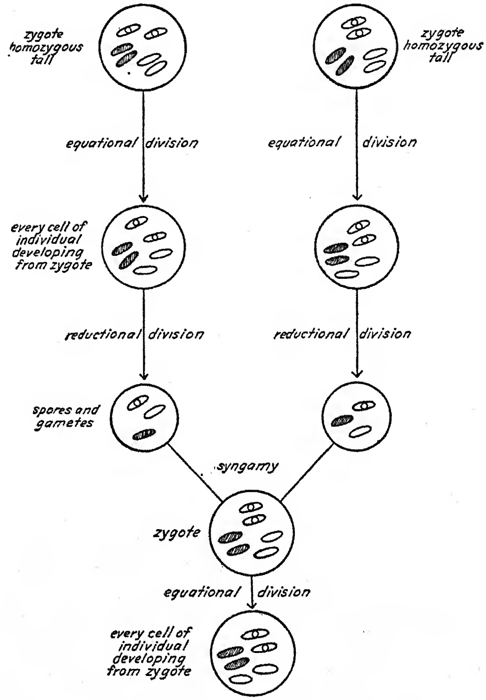


FIG. 347. Diagram representing the mechanism involved and results secured when two pea plants homozygous for tallness are crossed. O represents the gene for tallness. For convenience three pairs of chromosomes instead of seven are represented.

gametes, since all these are descended by equational divisions from these same daughter cells.

Since the reductional division separates the members of each *pair of chromosomes*, it also separates the members of each *pair of genes*. This is known as *segregation* of the genes. Of every pair of genes in the spore mother cell, one gene goes to one daughter cell and to the spores and gametes descended from it; the other to the other daughter cell and to the spores and gametes descended from it. If the two genes composing a pair of genes in which we are interested are identical—that is to say, if the parent is homo-

zygous for these genes—then the two daughter cells formed by reductional division are identical in regard to these genes. The same is true of the gametes descended from these daughter cells. If the pair of genes is composed of two different genes—that is to say, if the parent is heterozygous for these genes—then one daughter cell will contain one kind of gene, and the other daughter cell will contain the other kind of gene. The gametes, therefore, descended from these daughter cells will be of two kinds: half of them will contain one kind of gene, the other half will contain the other.

The union of gametes brings together again these gametes which may be alike or different, and again combines in one cell the two members, alike or different as the case may be, of the pair of genes which we are considering. This is known as the *recombination* of the genes. The new combinations may, as is shown below, resemble the combination which existed in the parents or differ from it.

232. **Parents Homozygous and Identical.**—When a homozygous plant is self-pollinated, or when homozygous and identical plants are crossed, the gametes descended from their reductional divisions are identical in gene content, and the pairs of genes of the new diploid individuals will be the same as those which existed in the parent. All the offspring, therefore, will be alike and like their parents. The effect of segregation and recombination in such plants is the same as that of equational division in vegetative reproduction. This corresponds, as we have seen, to the results obtained by breeding experiments.

A second genetical law, a summary of experiments and assumptions, expresses the results of the above discussion. It may be stated as follows: Homozygous plants when self-pollinated and homozygous plants or animals with identical genes when interbred breed true. We may center our attention upon one pair of genes and state as a corollary to this law that plants homozygous for any pair of genes when self-pollinated or interbred will breed true to the characters influenced by those genes (providing other genes also concerned with these characters are not heterozygous).

Here again, as in vegetative reproduction, occasional exceptions occur. Individuals are sometimes formed with a new character or group of characters; the new character being usually due to a change in a gene or to some abnormality in the distribution of chromosomes in mitosis. Such new characters are known as

mutations. Individuals possessing these new genes, if homozygous for them, breed true for them like any other homozygous individual. Thus a new line of descent may be established.

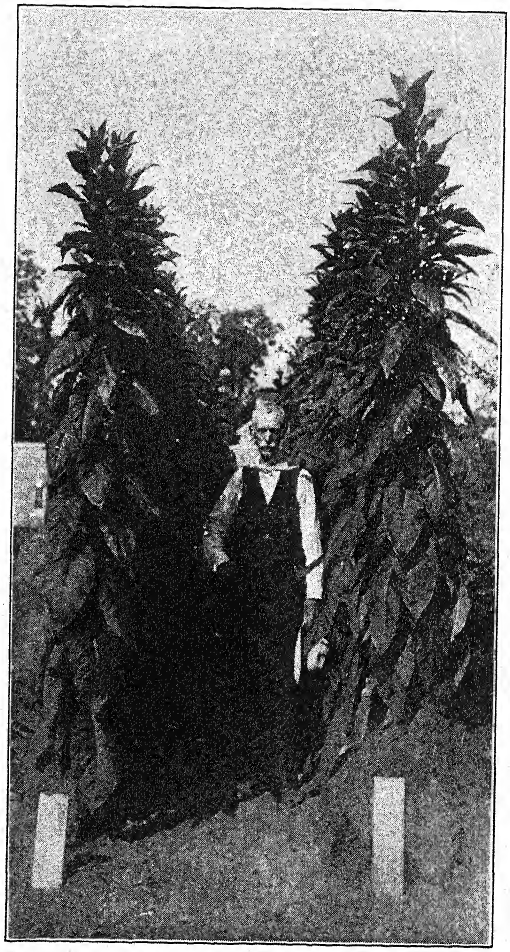


Fig. 348. A mutation of tobacco. The Stewart Cuban variety which appeared as a mutant from the Connecticut Cuban variety. (Courtesy of the Connecticut Agricultural Experiment Station.)

233. **Parents Homozygous but Different.**—Mendel found, when he crossed two homozygous pea plants which differed in some one characteristic, that the offspring resembled one parent and were all

alike in that respect. The mechanism here involved is as follows: Every cell of the tall pea sporophyte contains seven pairs of chromosomes. In one chromosome there is a gene for tallness, and in the corresponding chromosome of the same pair another similar

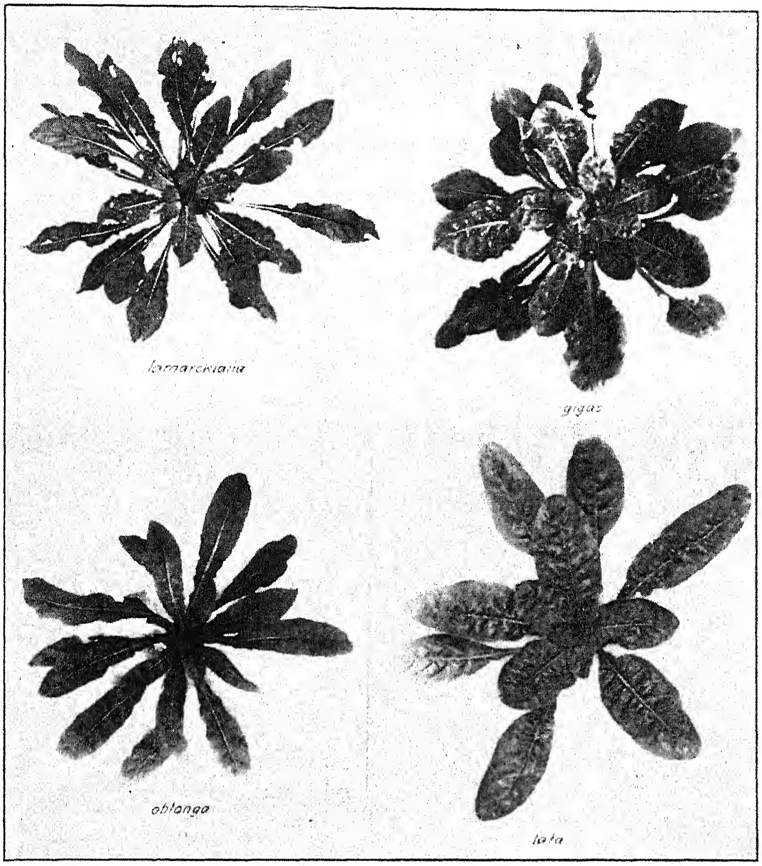


FIG. 349. *Oenothera Lamarckiana* and some of its mutants in the rosette stage. (Courtesy of B. M. Davis.)

gene. In every cell of the dwarf pea sporophyte there are likewise seven pairs of chromosomes. But the genes for tallness are lacking, and in their places on the corresponding chromosomes are two genes for dwarfness. Since they are descended from reductional divisions, every one of the gametes of the tall race contains seven

chromosomes, one of them containing a gene for tallness; similarly every one of the gametes of the dwarf race contains seven chromosomes, one of them containing a gene for dwarfness. The zygotes formed by the union of the two sorts of gametes all contain seven

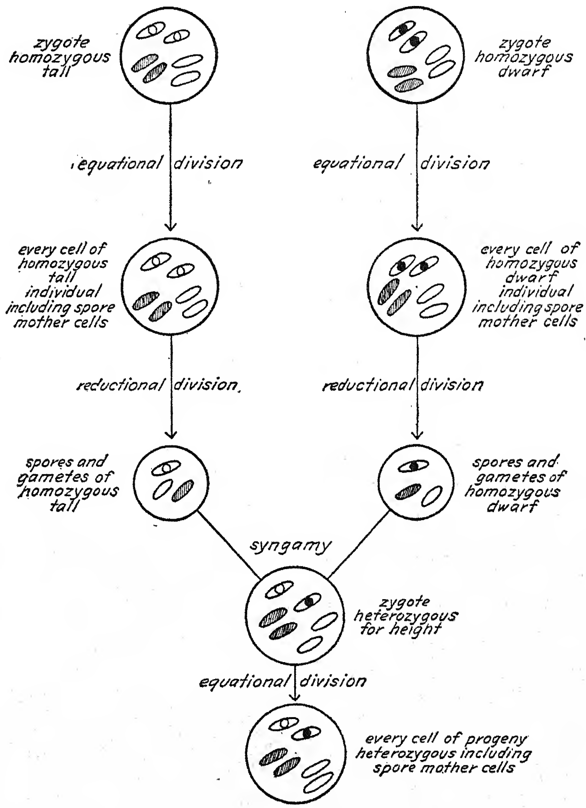


FIG. 350. Diagram representing the mechanism involved and results secured in crossing a homozygous tall pea plant and a homozygous dwarf pea plant. A white circle represents the gene for tallness and a black dot the gene for dwarfness. For convenience three pairs of chromosomes instead of seven are represented.

pairs of chromosomes, including one with a gene for tallness and a corresponding one with a gene for dwarfness. Both genes are present in the same cell. The same is true of every cell of the diploid individual which develops from each zygote. But, for some reason not yet understood, as the plant develops, the gene for tallness only is effective in influencing the height to which the

plant grows, and there is no visible effect of the other gene. The hybrid plants are therefore all tall, like the tall parent. Some pairs of genes do not exhibit this dominance, but both seem to coöperate in development, the result being a character intermediate between the parent types. The results may be expressed as a third genetical law as follows: When two varieties, races or strains of an organism which differ in characters and breed true for them are crossed the offspring will all be alike (so far as these characters

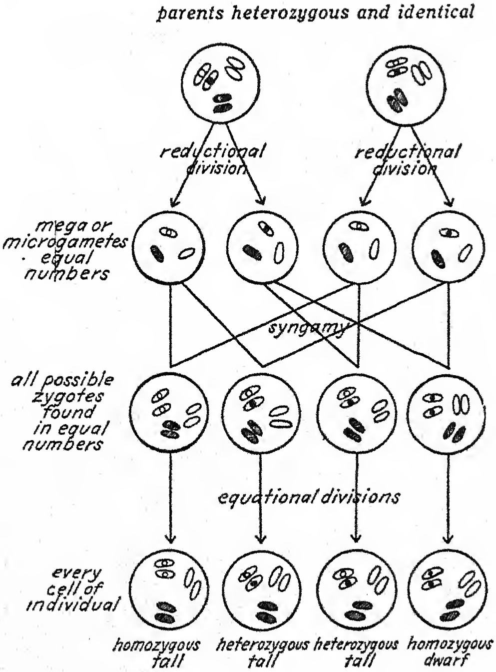


FIG. 351. Diagram representing the mechanism involved and the results secured in self-pollinating or interbreeding pea plants heterozygous for tallness. A white circle represents the gene for tallness which is dominant, and a black dot represents the gene for dwarfness which is recessive. For convenience three pairs of chromosomes instead of seven are represented.

are concerned) and will resemble one or neither of the parents. This law is limited to the hybrids produced by crossing homozygous individuals, or, if we consider individual genes, to the hybrids produced by crossing individuals homozygous for particular genes.

234. Parents Heterozygous for One Pair of Genes and Identical.—The explanation for the results obtained when a heterozygous individual is self-pollinated or two like heterozygous individuals are crossed (the three to one ratio) is as follows: It is evident that a plant heterozygous for tallness would produce, as the result of reductional division, megaspores of two kinds, one kind having the gene for tallness, the other having the corresponding gene for dwarfness. What is true of the megaspores should be true also of the megagametes—there should be two sorts and these two sorts should be in equal numbers. Likewise there would be two kinds of microspores and two kinds of microgametes and they should be produced in equal numbers.

For convenience we might represent the gametes with the gene for tallness by A and the gametes with the gene for dwarfness by a. Then of the megagametes half would be A and half a, and of the microgametes half would be A and half a. If such plants were self-pollinated or interbred, and if we assume that it would be purely a matter of chance with which kind of microgametes each kind of megagametes joined, then we would have the results indicated by the following combinations:

Microgametes	A	A	a	a
Megagametes	A	a	A	a
Zygotes	AA	Aa	Aa	aa

If we make all possible combinations and assume that each has an equal chance of occurring, then evidently the offspring resulting from self-pollinating or interbreeding plants heterozygous for one gene would be one-fourth homozygous for the dominant gene, one-fourth homozygous for the recessive gene, and one-half heterozygous for the genes concerned. But the homozygous dominant plants and the heterozygous plants are indistinguishable to the eye; the apparent ratio is three plants exhibiting the dominant character to every one showing the recessive. Since the mechanism involves chance, we would not expect the plants obtained to be exactly three-fourths of one kind and one-fourth of the other. As we have seen, the result of one of Mendel's experiments was a ratio of 2.84 to 1. The ratios in other experiments varied from 2.82 to 1 to 3.15 to 1, all approximately the expected 3 : 1 ratio.

These results and this mechanism may be summarized as a fourth genetical law: When an individual heterozygous for one pair

of genes is self-pollinated, or when two such individuals are crossed, the two kinds of genes segregate and recombine by chance, so that approximately three-fourths of the offspring exhibit the dominant character and one-fourth the recessive. Two-thirds of those showing the dominant character are heterozygous, one-third homozygous.

General Remarks

Reproduction by seeds involves reductional division and union of gametes; this means the segregation of genes and their recombination by chance. If the members of each pair of genes under consideration are alike, then nothing new results from these events; but if in any pair there are two sorts of genes involved, on corresponding chromosomes, then segregation and recombination give us new combinations of genes in a predictable ratio.

The explanations offered for the observed facts of inheritance by seeds include the following assumptions: The appearance of characters is conditioned by definite units, the genes, which are constant and pass into the daughter cells during reproduction; these genes exist in each cell in the diploid individual in pairs; if the two genes of a pair are not identical, one is dominant and one recessive (with some exceptions); previously to reproduction the two members of each pair separate, only one going into each gamete, and, in the union of gametes, come together again, the possible combinations being determined by chance. These assumptions compose a hypothesis which adequately explains the observed facts. If the hypothesis is true, then we can predict, using the same assumptions, what will be the result of self-pollinating the F_2 generation; all the recessive plants (being homozygous) should produce in the next generation nothing but recessive plants; one-third of the dominant plants (being homozygous) should produce nothing but dominant plants; and the rest of the dominant plants (being heterozygous) should give rise to offspring of both types in the ratio of three dominant to one recessive. This prediction is strikingly verified by further breeding, which therefore confirms the truth of the hypothesis. In the same way the results of any sort of cross can be predicted if we know what genes the parents contain; and the hypothesis has been verified again and again by the correspondence of the actual results obtained with the results expected according to the hypothesis. The same sort of logical procedure—the observation of facts, the making of assumptions to

explain the facts, and the testing of the assumptions by means of further facts—is used throughout science. It has led to our belief in molecules, atoms, and electrons, as well as genes.

More Complex Cases

If we self-pollinate a plant heterozygous for two pairs of genes and they are in the same chromosome, the results should evidently be no different from those given for one pair of genes. Cases of this sort are known in breeding experiments. If, however, the plant is heterozygous for two pairs of genes and they are in different chromosomes, then a different situation results.

If homozygous pea plants having smooth green cotyledons are crossed with others having wrinkled yellow cotyledons, the hybrids (called the F_1 or first filial generation) are all alike; as we would expect, since we have crossed homozygous individuals. (Law 3.) They are all plants with smooth yellow cotyledons, which shows that the genes for smoothness and yellowness are dominant. If these seeds are planted and the resulting individuals interbred or self-pollinated, the offspring (called the F_2 or second filial generation), if there are many, appear as follows: Out of every sixteen, nine look like the hybrid parents, having smooth yellow cotyledons; three are like one of the grandparents, having smooth green cotyledons; three are like the other grandparent, having wrinkled yellow cotyledons; and one is different from either parents or grandparents, having green wrinkled cotyledons.[8] Each of these classes judged solely by its appearance is called a *phenotype*. There are in this experiment four phenotypes.

The explanation of the mechanism involved and the ratios obtained is as follows: Let *A* represent the gene for smoothness and *a* the gene for wrinkledness, *B* the gene for yellowness and *b* the gene for greenness. Assume that the two pairs of genes are in separate chromosomes. The parents would be *AAbb* and *aaBB;* the hybrid *AaBb*. The gametes formed by the hybrid and the zygotes produced by crossing are shown in the following table.

[8] Mendel actually found in one such experiment—

Total	*Smooth yellow*	*Wrinkled yellow*	*Smooth green*	*Wrinkled green*
556	315	101	108	32
Ratio	9.8	3.1	3.4	1

		Microgametes (or Megagametes)				
		AB	*Ab*	*aB*	*ab*	
Megagametes	*AB*	*AABB*	*AABb*	*AaBB*	*AaBb*	
(or	*Ab*	*AABb*	*AAbb*	*AaBb*	*Aabb*	zygotes
microgametes)	*aB*	*AaBB*	*AaBb*	*aaBB*	*aaBb*	
	ab	*AaBb*	*Aabb*	*aaBb*	*aabb*	

Examining this table, we observe that there are in the zygotes nine different combinations of genes. Each of these, judged solely on the genes it contains, is called a *genotype*. There are in this

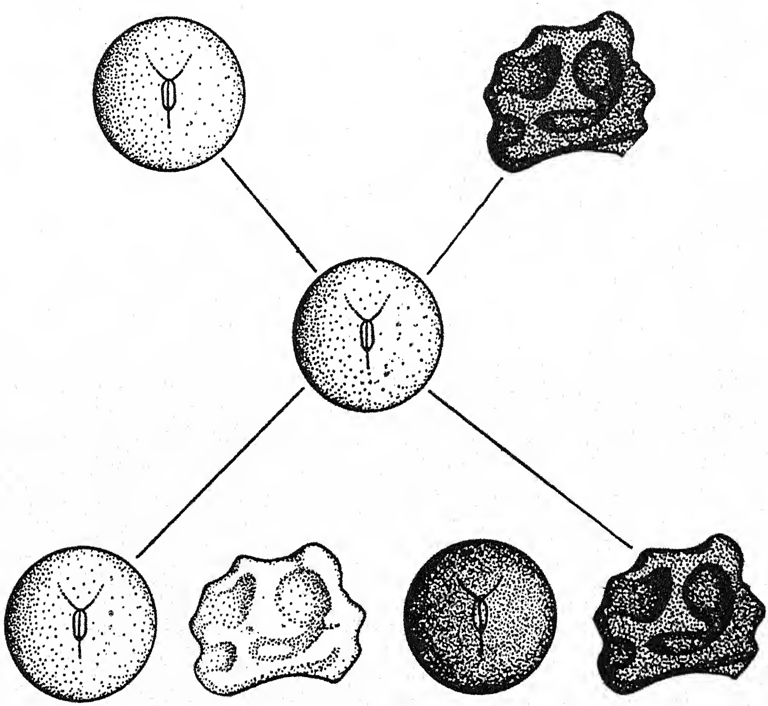


FIG. 352. Diagram showing the result of crossing homozygous plants which differ in two pairs of genes. A pea plant with smooth yellow cotyledons is crossed with one with wrinkled green cotyledons. The hybrid progeny (F_1 generation) all have smooth yellow cotyledons. The hybrid is self-pollinated and the phenotypes in its offspring (F_2 generation) are shown.

progeny nine different genotypes. Of the sixteen individuals represented in the table nine have both dominant genes and will therefore resemble the hybrid parent. One of these nine will

breed true. Of the others, two will breed true for smooth cotyledons, two will breed true for yellow cotyledons and four will breed like the hybrid parent. Six of the remaining seven individuals of the table have one of the dominant genes only—three of them the gene for smooth cotyledons and three the gene for yellow cotyledons. They will resemble the grandparents. Some will breed true (which are they?) and some will not (which are they?). One out of the sixteen has the recessive genes only and it will have green wrinkled cotyledons. It is different from parents and grandparents and will breed true.

This illustrates how it is possible by breeding to shuffle, so to speak, the characters and produce new types of plants. It shows also how recessive genes giving no indication of their presence in the parents may by self-pollination or interbreeding appear in the offspring. It is in this way that we can explain blue-eyed children of brown-eyed parents, and so-called "throw-backs," offspring which resemble in some characters distant ancestors. Perhaps this is the explanation for the bad sons of good parents, the proverbial minister's son.

The greater the number of genes (each in a different chromosome) for which a plant is heterozygous the greater will be the number of possible genotypes and phenotypes, as is illustrated in the following table.

Results of Inheritance in Self-pollinated Heterozygous Individuals
Complete Dominance and Recessiveness Assumed

Pairs of Heterozygous Genes in Separate Chromosomes	*Phenotypes (Pure Dominance)*	*Genotypes*
1	2	3
2	4	9
3	8	27
4	16	81
5	32	243
6	64	729
7	128	2,187
n	2^n	3^n

Since peas contain seven pairs of chromosomes it would be theoretically possible by self-pollinating or interbreeding individuals heterozygous in each chromosome for one or more genes to secure offspring having 2,187 different inheritances, which would result in

the development under uniform environmental conditions of 128 different appearing kinds of pea plants.[9] The Delicious apple contains fourteen pairs of chromosomes and, if we assume that each pair contains heterozygous genes, it is clear why the seeds of the Delicious apple are not used to propagate it and why it is propagated vegetatively, by budding or grafting.

By crossing and then self-pollinating or interbreeding it is possible to shuffle characters, making new combinations, and to bring out recessive characters not evident in the immediate parent or parents. By selecting and testing for homozygosity (how would such a test be made?) it is possible to determine which individuals showing the desirable combinations of characters will breed true. Time and much patient industry and a knowledge of plants are needed. It is by such methods that Burbank and other practical breeders have developed the new races and varieties of plants and animals which make their names famous.

A knowledge of the laws of genetics, only the more fundamental of which are presented here, makes it possible to shorten the time and decrease the labor. And trained geneticists are now annually adding new and desirable varieties to our ornamental and economically useful plants.

It is evident that a summary of the results of the inheritance where individuals heterozygous for more than one pair of genes are concerned is difficult to state simply and yet completely, because of the different degrees of heterozygosity which may exist and because the parents may be not only heterozygous but also different. In fact a large proportion of the science of genetics is devoted to summarizing the results of the inheritance of the offspring produced from heterozygous individuals and explaining the mechanisms involved. A group of laws rather than a single one is needed to cover such cases. However it can be said in general that when heterozygous individuals are self-pollinated, interbred, or crossed the offspring are of various types; some may resemble the parents, others may show various combinations of characters of the parents or characters not evident in the immediate parents but characteristic of earlier members of the line of descent. If the inheritance of the heterozygous parents and the dominance or recessiveness of the genes are known, it is possible to predict in a sufficiently large group of offspring the frequency of the occurrence of any particular

[9] Mendel actually secured this number of phenotypes by repeated crossing.

combination of genes and of the characters which they determine. The mechanism used to explain the results involves the assumption of genes arranged lengthwise in the chromosomes, the segregation of genes in reductional divisions, their continued existence as individuals during and after syngamy, and their influence upon one another.

To this general statement of inheritance in the reproduction of heterozygous individuals by seeds, which will without doubt appear to the student sufficiently complicated, some statement of exceptional cases should be added. We have assumed in our discussion that the set of genes in each chromosome segregates as a unit in reductional division. Such an assumption explains many of the observed results. There are results, however, which such a mechanism cannot explain, and it becomes necessary to assume that occasionally a part of one chromosome is exchanged for a similarly located part of its fellow. This has much the same effect as increasing temporarily the number of chromosomes. This is called "crossing-over," and is explained by assuming that an actual exchange of chromatin material occurs during reductional division, at a time when the paired chromosomes or the chromatin threads are closely associated.

Summary

We may summarize our present knowledge of heredity as follows: The biologic inheritance of an individual is the protoplasm, one or a few cells, which it receives from its parent or parents in reproduction and which is its beginning. In this protoplasm are certain bodies called genes which exert a profound influence upon the characters of the mature individual. They are arranged in the chromosomes like beads in a necklace. It is the presence of these genes which gives to the cell the power of differentiation. A fertilized frog's egg and a fertilized toad's egg look much alike. They are both spherical single cells. If both are placed in the same environment, one develops into a toad, the other into a frog. We explain the "toadness" of the toad egg and the "frogness" of the frog egg by assuming the presence of a set of genes in the toad egg which are different from those in the frog egg. Yet we do not know what a gene is nor how it produces its effects. We believe in them because in no other way can we explain the known facts of breeding, and because the theory of genes has proved to be consistent with an ever-increasing array of such facts. It is also

certain that the genes in the chromosomes are not the only things in the cell concerned in inheritance. The inheritance of an individual includes other material than the chromosomes—for instance cytoplasm. There are things in the cytoplasm just as important in inheritance as the genes in the chromosomes.

FIG. 353. A genetically dwarf and a normal corn plant grown in the same environment (compare Fig. 70). (Courtesy of J. H. Kempton and United States Department of Agriculture.)

The presence of a gene does not mean that the organism will necessarily develop a particular character. It merely indicates that the organism has the potentiality or possibility of developing the character associated with that gene. A plant may have a gene for tallness, but it will nevertheless be stunted if the plant is grown with a limited water supply; on the other hand some plants fail to develop into tall plants even in the most favorable environment because they lack the gene for tallness. Genes, together with the rest of the protoplasm, deter-

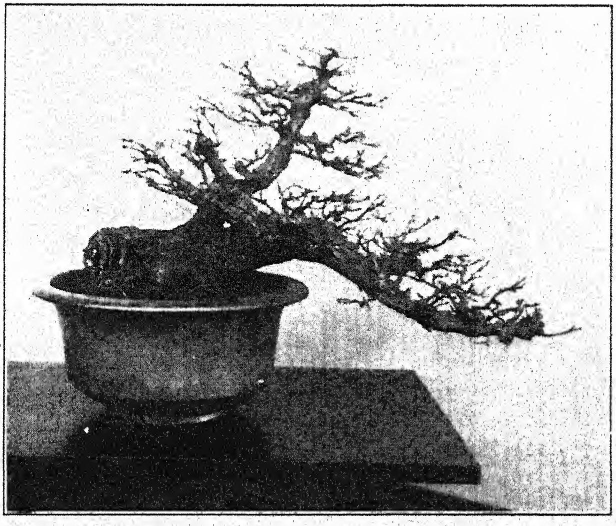


FIG. 354. An environmentally dwarfed plant. A maple tree, *Acer palmatum*, 30 years old and 1 foot $8^1/_5$ inches in length. (Courtesy of Goro Ida.)

mine the capabilities or possibilities of development; the final result depends also on the environment. Neither the protoplasmic contents of a cell nor the environment can by itself effect any development at all.

The characters of the mature individual are the result of complex reactions involving all the inheritance (the parts of the nucleus and cytoplasm) and the environment. The inheritance of an individual depends upon the sort of nuclear divisions (equational or reductional) involved in the formation of the cells which it receives from its parents and whether gametic union is concerned

FIG. 355. An environmentally dwarfed plant. A pine tree, *Pinus Thunbergii*, 20 years old and 1 foot $3^1/_2$ inches in height. (Courtesy of Goro Ida.)

in its origin. The assumptions regarding genes, their importance as determiners of characters and their location in the cell and the known facts of cell division and reproduction enable us to predict the character of the offspring if we know what genes the parents contain, and if the cytoplasm and the environment remain constant.

CHAPTER XXVI

Biologic Evolution

Our study of living things reveals certain facts or groups of facts which rouse our curiosity and demand some sort of explanation.

235. The Great Number of Kinds of Plants.—We cannot fail to be impressed with the great number of different kinds of plants. There are at least 233,000 different species known and named, not including the races and varieties of a particular species. The botanist calls the apple one species, but there are many distinct varieties of apples. Where did all these sorts of plants come from? How did they originate?

236. The Arrangement of Kinds of Plants in Series.—Another interesting fact is that although two particular species of plants may not resemble one another closely we can find other sorts of plants which more or less completely bridge the gap between the two—forming a series of intermediate forms. A typical Spermato-

	Spermatophytes	*Ginkgo and Zamia*	*Fossil Seed Ferns*	*Selaginella*	*Pteridophytes*
Non-motile microgamete....	(+)	(−)	(−)	(−)	(−) Motile microgametes
Pollen tubes...............	(+)	(+)	(−)	(−)	(−) No pollen tubes
Seeds......................	(+)	(+)	(+)	(−)	(−) No seeds
Heterosporous.............	(+)	(+)	(+)	(+)	(−) Homosporous
Parasitic gametophyte......	(+)	(+)	(+)	(+)	(−) Independent gametophyte
Independent sporophyte....	(+)	(+)	(+)	(+)	(+) Independent sporophyte
Fibrovascular bundles......	(+)	(+)	(+)	(+)	(+) Fibrovascular bundles

Diagram showing that *Ginkgo* and *Zamia*, the Fossil Seed Ferns and *Selaginella* partially bridge the gap between a typical Spermatophyte and a typical Pteridophyte (fern).

phyte, for example the lily, and a typical Pteridophyte, a fern, have little in common. Both have fibrovascular bundles and both have independent sporophytes with spores in sporangia on sporo-

phylls; but the lily has a parasitic gametophyte, the fern an independent one, the lily is heterosporous, the fern homosporous, the lily forms pollen tubes, the fern has none, the lily forms seeds, the fern does not, the lily microgametes are non-motile, those of the fern are motile. However, there are plants, for example *Zamia* and *Ginkgo*, which are like the lily in having parasitic gametophytes, in being heterosporous, in forming pollen tubes and seeds, and like the fern in producing motile microgametes. There are others, for example *Selaginella*, which resemble the lily in having parasitic gametophytes and being heterosporous and like the fern in forming no seeds nor pollen tubes and in having motile microgametes. And among fossils we find curious plants of which living examples no longer exist which resembled the ferns in many ways but produced seeds.

Within the great groups also we can find intermediate forms between the extremes. The mock pennyroyal (*Hedeoma*) is classi-

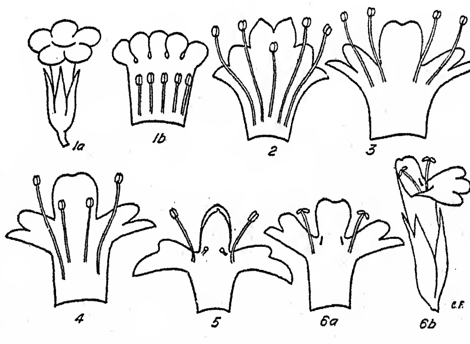


FIG. 356. Flower forms intermediate between the forget-me-not and the mock pennyroyal. *1a*, forget-me-not, *Myosotis; 1b*, the same, corolla split open and spread apart to show the stamens; *2*, viper's bugloss, *Echium vulgare; 3*, water mint, *Mentha aquatica; 4*, thyme, *Thymus; 5*, sage, *Salvia; 6a* and *b*, mock pennyroyal, *Hedeoma.*

fied with the family of Angiosperms called Labiatae. Its flower is two-lipped (bilabiate), the upper lip being made of two fused petals and the lower of three, the whole forming a tubular corolla. Within the corolla and attached to it there are two perfect stamens and two short filaments without anthers; or there may be two stamens only. The forget-me-not (*Myosotis*) is placed in the family Boraginaceae. It too has a five-lobed tubular corolla, but the lobes are all equal, and there are *five equal* stamens attached to the

inner surface of the corolla. Structurally these two flowers are quite different. In these two families, however, there are intermediate forms. The flower of the viper's bugloss (*Echium vulgare*), which is placed in the Boraginaceae, is somewhat two-lipped, the upper and lower sides of the flower being distinctly different, though not enough to form two very distinct lips; and some of the Labiatae, for instance the spearmint (*Mentha spicata*), have corollas which are nearly regular. The condition of the stamens in the flowers of these two families is still more interesting. In the forget-me-not there are five equal stamens, in the viper's bugloss the middle stamen is shorter than the other four, in the spearmint there are four equal stamens,[1] the flower of the wild thyme (*Thymus*) has four stamens of which two are shorter than the others, in the sage (*Salvia*) there are four of which two are very short, and in the mock pennyroyal there are two stamens

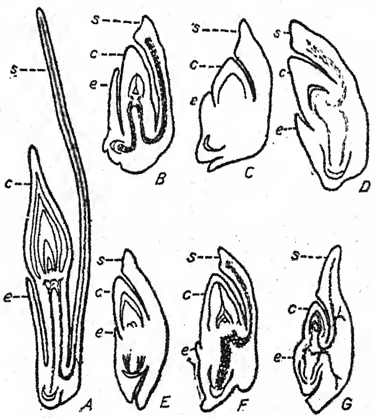


FIG. 357. Diagrams of longitudinal sections of a series of grass embryos (Gramineae) ranging from one with a well developed epiblast to one with little or none. *A*, *Zizania aquatica; B*, *Leersia clandestina; C*, *Leptochloa arabica; D*, *Triticum vulgare; E*, *Spartina cynosuroides; F*, *Triticum vulgare; G*, *Zea Mays.* *s*, scutellum; *c*, coleoptile; *e*, epiblast. (From Gager, *General Botany*, P. Blakiston's Son & Co.)

with rudiments of two more, or two stamens only. It is possible then to find in these two families of the Angiosperms a series of flowers which bridge the gap between one with a regular corolla

[1] In the beard tongue (*Pentstemon*), belonging to another family, the Scrophulariaceae, there are four perfect stamens and one, the middle one, which has no anther but consists of a filament only.

and five stamens and one with a bilabiate corolla and two stamens only.

Similarly it is possible to find a series of forms intermediate between the dicotyledonous embryo and the typical monocotyledonous embryo.

All of this shows that it is possible to arrange the kinds of plants in a series. While the extremes may be quite different, intermediate forms permit us to pass by small steps (with greater or smaller gaps) from one extreme to another. The existing gaps may always have existed; or they may be accidental only, due to our incomplete knowledge of living and fossil plants, or to the disappearance of the intermediate forms from the earth.

237. **The Practical Importance of This Principle.**—From such series it is possible to state the principle that between extremes of plant form there probably exist or have existed plants of intermediate form. On the basis of this principle, Hofmeister predicted that inside the pollen tubes of some Spermatophytes motile microgametes would be found, although at that time no such thing had ever been observed. Twenty years after his death this prediction was fulfilled by the discovery of the motile microgametes of *Zamia* and of *Ginkgo*.

238. **Adaptation.**—The third fact, which has been discussed earlier, is the adaptation of the plant to its surroundings. One of the most obvious adaptations is that stems grow upward into the air where the leaves are advantageously placed for photosynthesis and roots grow downward into the soil where water and mineral salts are found. Hundreds of other adaptations might be cited. Some are so wonderful that we are tempted to assign to the plant sentient powers for which we have no justification; a plant is not, as far as we know, able to plan nor to foresee future happenings. Some of the most remarkable of these adaptations are concerned with cross-pollination.

The pollen of a certain orchid (*Catasetum saccatum*) is found in two waxy masses fastened by a short stalk to a sticky disc. This entire structure is fastened to an upright column situated within the flower. The disc and pollen masses are held in cavities in the column; the connecting stalk bends from one cavity to the other and is in a state of tension. From the column two antennae project down over the lower petal or labellum, which is fleshy and sweet tasting. When an insect feeds on the labellum it touches

one of the antennae and this stimulus causes the disc to spring out of its cavity, dragging the pollen masses after it, with a force sufficient to project them two or three feet. The disc travels first

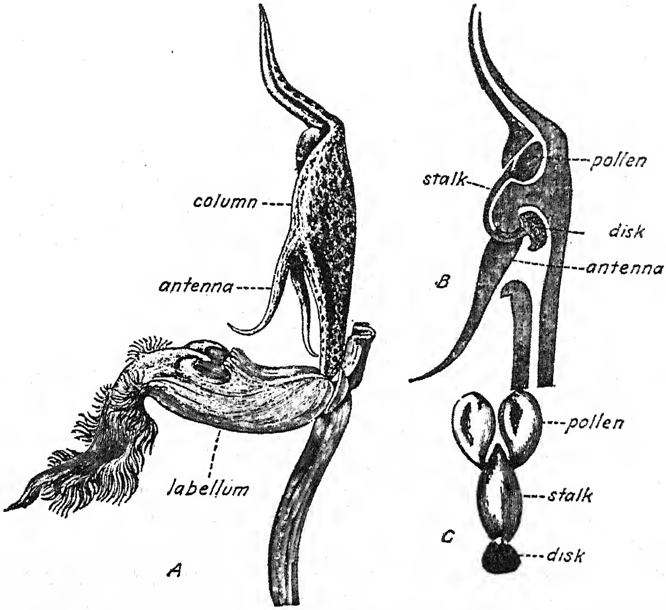


FIG. 358. An orchid, *Catasetum saccatum*. *A*, side view of flower with all the sepals and petals removed except the labellum; *B*, diagrammatic section through the column with all the parts a little separated; *C*, the pollen masses, stalk and disk, re-removed from the flower and somewhat enlarged. (From Darwin, *Fertilization of Orchids by Insects*, D. Appleton Co.)

and, if it strikes the insect, adheres to its back, the stalk and two pollen masses standing upright in a suitable position for touching the stigma in the next pistillate flower visited.

The pollen of the *Yucca* flower is a sticky or waxy mass which cannot be carried by the wind. The only known means of pollination is a type of moth, the *Pronuba* moth. The insect collects pollen from one flower, carries it to the stigma of another, and there presses it securely down. It then lays an egg in the ovary of that flower. The larva which hatches from the egg feeds on some of the seeds which would not have developed without the pollination. Without the *Pronuba* moth the *Yucca* would not produce seeds and without the seeds of the *Yucca* the insect would not long con-

tinue to exist. It is easy—but unscientific—to assign to both flower and moth the ability to plan, to foresee, and to act accordingly. But the scientist must search for facts with which to explain such a marvelous phenomenon.

239. **Special Creation.**—One explanation for all these facts is that each of the different sorts of living things was created independently. They are adapted to their environments because they

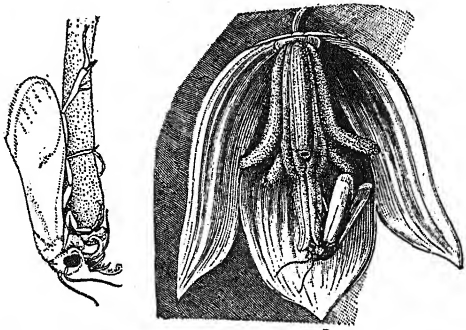


FIG. 359. *Yucca* flower and *Pronuba* moth. *A*, *Pronuba* moth collecting pollen from a *Yucca* stamen; *B*, moth depositing pollen on stigma. (*A* from Ganong, *Textbook of Botany for Colleges*, copyright 1916 by The Macmillan Company; reprinted by permission. *B* from Kerner, *Natural History of Plants*, Henry Holt & Co.)

were made that way in the beginning. The different sorts resemble one another because that is the way in which they were made. This idea is sometimes called the *Theory of Special Creation.* In its narrowest interpretation this theory includes the idea that not only was each kind of living thing made independently but it has remained unchanged since then; the living world is today as it was when first created. This was the commonly accepted explanation previous to the early part of the nineteenth century.

239. **Fossil Plants.**—Certain observable facts make such an explanation seem impossible. Many fossils have been found of plants which no longer exist. Fossils of plants which look much like the plants of today are numerous but fossils of plants which are identical with those of today are less numerous. The lower and therefore older earth strata yield fossils of certain groups of plants, such as the algae, and not those of other groups, such as the Angiosperms, which appear in later strata. These facts indicate that the plants of today are not the same as those of past ages.

The same is true of animals. If time could be rolled back to the period when the coal measures were laid down, the flora and fauna would be strange to us. Some of the dragon flies of that time had a wing spread of as much as two feet. The reptiles, some of them gigantic in size, were of numerous kinds and different from any that live now. The forests were not walnut, oak, maple and hemlock, but giant club mosses, scouring rushes, tree ferns, conifers and cycads, many of the kinds of which no longer exist. All this is preserved for us to read in the fossil record.

The oldest [2] earth strata with which we are acquainted are those of the era called Archeozoic, and in them not a single recognizable trace of life has been found, though this period occupies approximately 30 per cent of geologic time. In the rocks of the next geologic era, the Proterozoic, no fossil plants except bacteria and small types of algae have been found, and bacteria and algae

FIG. 360. Composite restorations of Carboniferous trees. *Lepidodendron* in right foreground; *Sigillaria* in left foreground; *Cordaites* and tree fern in background; *Calamites* in outer circle. (From Chamberlain and Salisbury, *Textbook of Geology*, Henry Holt & Co.)

only are found in the rocks of the Cambrian, Ordovician, and Silurian periods of the Paleozoic era. The oldest strata in which fossils of vascular land plants have been discovered are those of the Devonian period. But to one familiar with those of today these plants appear "strange, crude, unnatural and altogether forbidding." They include simple rootless and leafless plants reproducing by spores, spore-producing fern-like plants, *seed-producing* tree-fern-like plants, horsetail-like plants ten feet or more

[2] Judged so by their lower position relative to other strata.

high, and conifer-like trees. Several thousand species of fossil plants have been found in the rocks of the Carboniferous period. Fossils of ferns and seed ferns are the commonest. Carboniferous plants included also the Lepidodendrons—Lycopodium-like plants 100–175 feet high; the Calamites—giant horsetail-like plants; the Cordaites—resembling in some respects the tree Yuccas but one hundred feet in height; and conifer-like trees. In the rocks of the Triassic and Jurassic periods of the Mesozoic era fossils of cycads,

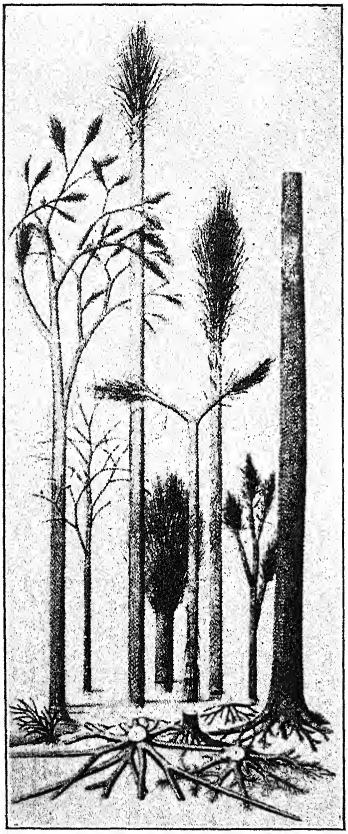


FIG. 361. Restoration of Carboniferous trees. Two on left side are *Lepidodendrons;* all others are different types of *Sigillaria;* types of *Stigmaria* in foreground. (After Grand'Eury from Knowlton, *Plants of the Past,* Princeton University Press.)

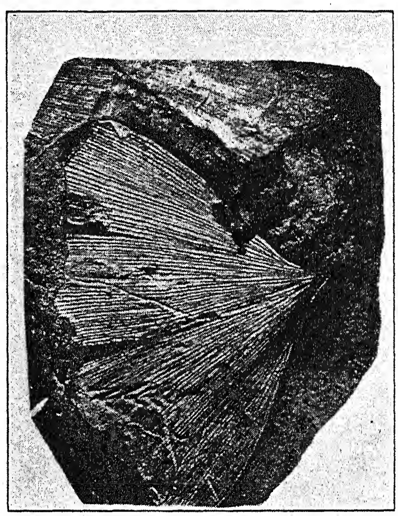


FIG. 362. Fossil of a leaf of the maidenhair tree (*Ginkgo digitata*). (From Knowlton, *Plants of the Past,* Princeton University Press.)

conifers, and ferns are most abundant, although algae, small horsetails, small lycopods, and moss-like plants are also found. In the rocks of the Jurassic period fossil *Ginkgo* leaves have been

discovered identical in appearance with the leaves of the *Ginkgo* trees now living.

No fossils recognizable as those of Angiosperms have been discovered in rocks earlier than the Mesozoic era. From then on fossils of Angiosperms become more and more abundant and include greater and greater numbers of plants identical with those of the present. In the clays and sands which extend from Martha's Vineyard, Massachusetts, to the Potomac River, and which belong to the Upper Cretaceous period, is the Raritan flora. It comprises nearly three hundred species, which include twenty ferns and cycads, fifty conifers and more than two hundred Angiosperms. There are three species of tulip-tree (*Liriodendron*)—now represented by one or possibly two species, four or five kinds of *Sassafras* —there is but one species now living, nine species of *Magnolia* or more than now live in all North America, six species of persimmons (*Diospyros*), nine species of bayberries (*Myrica*), and seven species of *Eucalyptus*, now native only in Australia. Compare this with the fossil flora of the later Pleistocene epoch from the west coast of Sussex, England, which has yielded fifty species, all of which are still living in England. They include the English oak (*Quercus Robur*), cornel (*Cornus sanguinea*), elder (*Sambucus nigra*), wild cherry (*Prunus Padus*), and hazel (*Corylus avellana*).

241. Development of New Kinds of Plants in Historic Time.— Another group of facts which makes the Theory of Special Creation (as stated above) seem improbable is the production of new kinds of plants in historic times by the gardener, horticulturist, and plant breeder. To develop new and better kinds of grains, fruit trees, and potatoes is one of the main ambitions of many farmers and agricultural scientists; and their efforts have often been successful. The record of the origin of many kinds and varieties of plants is incomplete, lost in the dimness of antiquity. The history of the sweet pea, *Lathyrus odoratus*, however, as a horticultural plant is known from the beginning. The original sweet pea was in 1700 much similar in general habit to the cultivated peas of the present day. The flower stems, however, were short and bore but two flowers, relatively small, with an erect or reflexed standard and conspicuous depressed wings. In color the standard was reddish purple and the wings light bluish purple. From this original form there evolved in the next 100 years a white variety, a pink and white, a scarlet, a dark violet, and a blue. In 1700

Principal Divisions of the Sedimentary Rocks of the Earth's Crust, Arranged in Ascending (Natural) Order. (After Knowlton)

Era	*Period*	*Epoch*	*Maximum Thickness*
Cenozoic era 4% of geologic time	Quaternary	Recent Pleistocene	5,000 feet of clay, sand, and gravel
	Tertiary	Pliocene Miocene Eocene	32,000 feet of clay, sand, gravel, sandstone, limestone, and coal
Mesozoic era 11% of geologic time	Cretaceous	Upper Lower	65,000 feet of sandstone, shale, limestone, and coal
	Jurassic		
	Triassic		
Paleozoic era 30% of geologic time	Carboniferous	Permian Pennsylvanian Mississippian	70,000 feet of shale, sandstone, limestone, and coal
	Devonian Silurian Ordovician Cambrian		
Proterozoic era 25% of geologic time	Keweenawan		30,000 feet of conglomerate and sandstone, with lava
	Animikian		14,000 feet of banded slate, and schist, with iron ore
	Huronian		10,000 feet of glacial conglomerate, quartzite, and limestone
	Sudburian		20,000 feet of quartzite
Archezoic era 30% of geologic time	Keewatin		100,000 feet of sedimentary schist, gneiss, lava, slate, and limestone
	Grenville		

there was only *one* kind of sweet pea, in 1806 there were *five* kinds. Now there are over *500* entirely distinct colors, tints, shades and combinations within the Spencer or waved form alone. Many other similar histories could be cited, for example the development of many varieties from the original Boston fern, which in turn came from a wild tropical fern.

242. **Biologic Evolution.**—The situation revealed by the fossil record and by the development of horticultural varieties in historic time has been summarized in the statement that the kinds[3] of plants and animals which exist today developed from other kinds which existed in times past. By this we mean that the new kinds have developed in the reproduction of old kinds through a change of some sort in the nature of the living stuff, protoplasm. This statement is called *Biologic Evolution.* It is a summation of observable facts. The living world of today is not the same as it was ages ago and may not remain as it is now. We do not know from how many original kinds of living things the present numerous and varied assortment evolved. Some assume that there was originally a considerable number of different kinds while others think of all living forms as being descended from one or a few original ancestors. The geologic record has led most scientists to assume that the original forms of life were structurally simple—probably one-celled, amoeba-like, bacterium-like, or *Protococcus*-like. From these kinds of living things, in the course of time, other and different forms gradually evolved. Evolution, which is a summary of facts which anyone may observe who cares to, explains why plants can be arranged in a series. Each new kind was derived from some previously existing kind and therefore resembled it more or less closely. The longer evolution continues the more the new kinds may differ from the original types. The new forms which continue to exist and to propagate their kind must be adapted to their environment or they perish. A plant whose leaf-bearing stems grew down into the earth and whose roots grew up into the air could not continue to exist.

243. **Course of Evolution in Plant Kingdom.**—The course of evolution in the plant kingdom is still a very unsettled matter and one of the large problems of Botany. There are large gaps in all of the proposed evolutionary sequences, particularly between

[3] The original kind or kinds from which the new sorts were derived may still exist or may have perished in whole or in part.

the Thallophytes and the Bryophytes and between the latter and the Pteridophytes. A diagram of possible relationships and evolutionary connections between some of the groups of plants is shown in Figure 364.

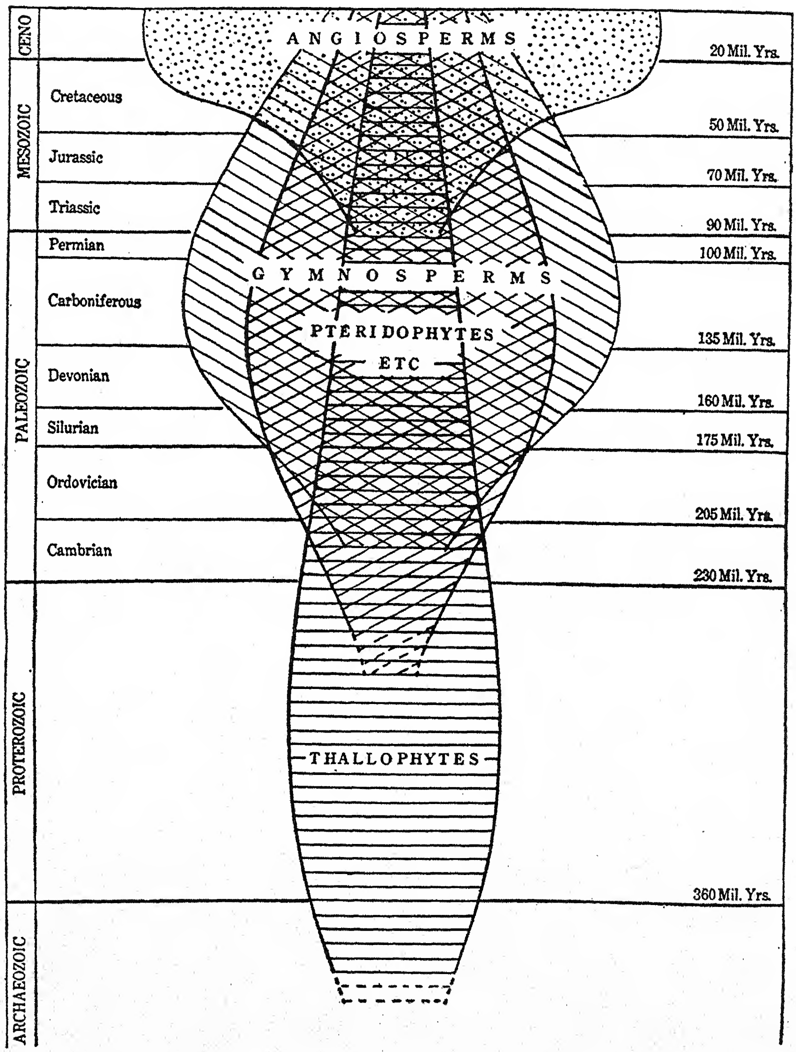


FIG. 363. Diagram showing possible times of origin and relative abundance of the great groups of plants in geologic time, as judged from the fossils. (After Berry from Swingle, *Textbook of Systematic Botany*, McGraw Hill Book Co., Inc., New York, N. Y.)

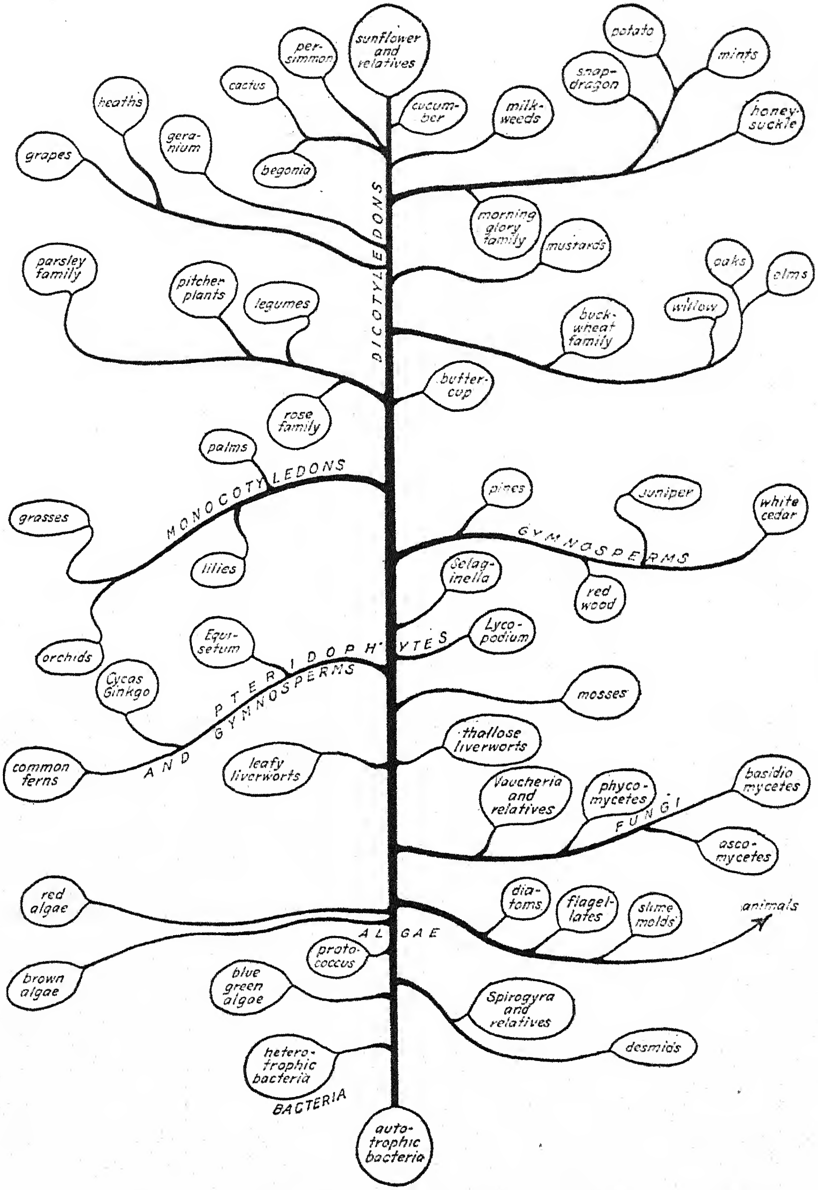


FIG. 364. Diagrams of possible evolutionary relationships of some of the group of plants. (Based on chart by Mez and Ziegenspeck, in Botanisches Archiv.)

244. Geographical Distribution.—Evolution enables us to explain the first facts mentioned in this chapter and many others which would otherwise be unrelated. A reasonable explanation for many of the puzzling facts of the *geographical distribution* of the various kinds of plants and animals can be offered in the light of evolution. A study of the flora and fauna of certain islands, such as the Galapagos islands, shows that the plants and animals on these islands are much like but not exactly like those of the neighboring South American mainland. We may of course say that this is so because the plants and animals on the mainland and on the islands were made that way in the beginning and have remained in their original condition. Knowing, however, that living things do evolve, it is possible to assume that at some time in the past animals and plants from the mainland reached the islands and then the two groups separated by the sea evolved, each somewhat differently, with the result that the kinds now on the islands resemble those on the mainland but are not identical with them.

This is beautifully illustrated also by the flora (and fauna) of the Hawaiian islands. These islands, with a combined area of 6,454 square miles, are further removed from any continental area than is any other region of equal size. They are 2,000 miles from North America, the nearest continent, and 1,860 miles from the nearest islands of any importance, the Marquesas. The enormous depths (10,000 to 20,000 feet) of the ocean surrounding these islands indicates that they have always been thus isolated, or for a very long period of time. Five hundred and seventy-four of the species of the seed plants present on the Hawaiian islands out of a total of seven hundred and five are peculiar to those islands and found nowhere else in the world. The geologically older islands of this group have the greater number of endemic species. The Lobelia family forms one of the most marked features of this flora. There are one hundred and forty-nine species, varieties and forms of this family peculiar to the Hawaiian islands; these belong to seven genera, six of which have representatives nowhere else. Most of these plants are woody, some are epiphytes, some almost tree-like, twenty or thirty feet high. The peculiarity of this flora is readily explained by assuming that it has evolved from a few original species derived from neighboring continents and subsequently isolated.

245. Comparative Morphology and Physiology.—The similarities

in the *comparative morphology* or *anatomy* of such a series of forms as the flowers or monocotyledonous embryos previously described can be understood by assuming that one kind has evolved from another or from a close relative. In the natural system of classification plants are grouped according to similarities in comparative morphology and anatomy, especially that of the reproductive organs. The kinds of plants within these groups (families or genera) show resemblances also in their *comparative physiology*[4] as in their morphology. For example most of the species in the Mint family form aromatic oils; the members of the Mustard family (radish, mustard, cabbage, water cress) contain pungent chemical substances which give them their characteristic flavors; many of the Nightshade family (black nightshade, tobacco, jimson weed) develop poisonous alkaloids. The species within a group can often be successfully grafted, but members of separate groups cannot be. The apple, the pear and the quince (Rose family) can be grafted one on another, and so can the orange, the lemon and the grapefruit (Citrus family), but a twig of an orange tree cannot be successfully grafted upon an apple tree. On the basis of evolution we consider the plants in a group related; for similarities in the morphology and physiology of related kinds of plants are to be expected.

Because all these facts can be explained by evolution they are frequently cited as *proving* the theory of evolution. They do not necessarily do that. A theory is *proven* only when the observed facts can be explained *in no other way* that we can imagine. Special Creation may be offered as an explanation for the facts just referred to (embryology, geographic distribution, etc.). The only *direct proof* of evolution is the evidence of our eyes today in the matter of plant and animal improvement; that surely can be interpreted in no other way. All the other evidence then tends to confirm the truth of evolution, since it is in harmony with it.

The Method and Cause of Evolution

While there can be no question that living things have evolved and are still doing so, the explanation of just how and why this

[4] There is a group of facts in *embryology*, the development of the individual, which are explainable by evolution. The embryological development of an individual, particularly that of an animal, frequently shows stages similar to those of less highly differentiated organisms. This is sometimes summarized by saying that the individual recapitulates in his development the evolutionary history of the race.

occurred (*i.e.*, the method and cause of evolution) is still incomplete. Several explanations have been offered, to all of which important objections have been made.

246. **Lamarck's Explanation.**—One of the earliest explanations was suggested by Lamarck. His explanation is simple and plausible. It is based on the familiar fact that a plant or animal during its lifetime becomes adaptively modified in response to environmental conditions. If we should take two peas from the same pod and plant one in a moist soil and the other in a dry soil, the plant which develops in the moist habitat would have thin broad leaves with little cutin, and the one in the arid habitat would have small thick leaves with a heavier cuticle. Such a change in form would better fit the latter for survival under the conditions of the arid habitat. A man engaged in severe manual labor develops muscles which fit him for that sort of life. These changes in the *normal* form or physiology of an organism, which occur in response to its environment, are called *acquired characters*. As in the examples just described, acquired characters are very commonly beneficial to the organism, adapt it better to continued life in its particular environment. Lamarck assumed that the capacity of developing these acquired characters was passed on to an intensified degree to the offspring. The progeny of the individual plant which developed under the arid conditions would, according to Lamarck, be better able to develop the characters which protect the plant against drought than the progeny of the plant which grew in the moist habitat. In time, therefore, we would have, according to Lamarck's idea, two kinds of peas, one adapted to a moist habitat, the other to an arid one; and even if these two kinds were planted in the same soil each would retain its peculiarities, though to a smaller degree. Lamarck's explanation would permit the development, in time, of new species with an increased degree of adaptation. In Lamarck's explanation the necessity for the modification was the cause for its appearance and the method was the summation by inheritance of successive modifications. Attractive as this theory is, the experimental evidence for the inheritance of acquired characters is at present almost negligible, and there is considerable evidence to the contrary.

247. **Darwin's Explanation.**—Darwin's explanation was based upon two facts which anyone can confirm. First, he observed that the progeny of any parent or parents are not all alike; they

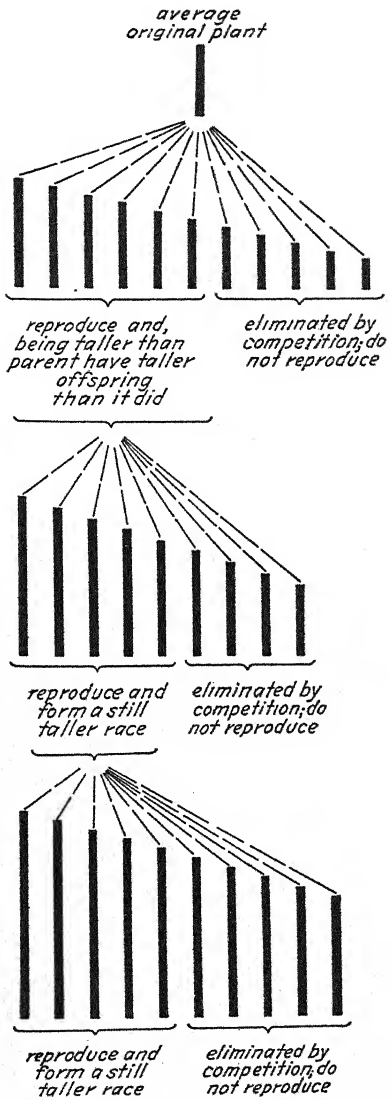


FIG. 365. A diagram illustrating Darwin's theory of evolution. The different sizes of lines represent different sizes of plants. The tall plants are assumed to have the best chance of survival in the "struggle for existence."

show small variations. So in a crop of beans some will be larger than others, and, when planted, the plants which grow will not all be of the same size. In a litter of puppies some will be swifter than others, or of keener sense of smell. Second, he observed that most kinds of plants and animals produce enormous numbers of progeny, so many in fact that if they all survived there would soon be no room on the surface of the earth for them. A moderate-sized fern produces in one year about 50,000,000 spores. If each of these spores produced a gametophyte and it gave rise to a new sporophyte, and if each plant occupied a square foot, the progeny of a single plant in one season would cover 50,000,000 square feet or $1\frac{2}{3}$ square miles. If each of these plants in turn reproduced as before and all survived, the progeny of one fern plant would occupy in two seasons an area equal to the entire North American continent. But, of course, all of the progeny of a fern do not survive, because the plants interfere with each other and are interfered with by the progenies of other plants. The enormous reproductive capacity of plants and animals results in a continued struggle between individuals, between species, between groups, for food, light, air, water and the conditions for life in general. These are *facts*. Darwin *assumed* that the small variations were inherited; that the progeny of the big bean of a given lot would be bigger than those of a small bean; that the descendants of the swifter dog of a litter would be swifter than those of the slower dog of the same litter He also assumed that the struggle for survival would eliminate those less fitted to the environment. By these two assumptions he therefore accounted for the origin of new kinds of plants and animals and their adaptations to their environment. Darwin's explanation of the method of biologic evolution is weakened if not destroyed by the evidence, which has accumulated since his time, that most of the small variations are not inherited (see p. 411); and by the fact that the differences between many kinds of plants and many kinds of animals are so small that it is impossible to see how they could be of any significance in determining survival. Certain kinds of insects, for instance, differ only in the number of some small hairs on their bodies. Of course it may be possible that those minor morphological differences are merely evidences of more profound physiological differences of which we do not know. Darwin's explanation concerns the method of evolution only, which he thought to be the summation of small modifications by inheritance. The cause of the original modifications he did not explain.

248. Evolution through Mutations.—Hugo de Vries observed that there were two kinds of variations in offspring, one sort which is not inherited and an heritable sort. The latter are called *mutations*. Mutations, so far as our observations go, are not numerous and they are not always adaptive. They may, indeed, be so pathologic as to insure early death to the individual possessing them. The method of evolution on this basis would be much similar to that pictured by Darwin, with mutations instead of the commoner fortuitous variations furnishing the new varieties. It would appear, however, extremely difficult to explain on such a basis the extraordinary precise adaptations such as that described for the *Yucca* plant and the *Pronuba* moth.

249. Evolution through Hybridization and Selection.—There is also the explanation that new species or races originated through natural hybridization and the juggling of characters in Mendelian inheritance. New races of plants have been produced experimentally by the application of such methods by Burbank and by many other less well-known plant breeders. However, a race or kind which will perpetuate itself and will not hybridize with the kinds from which it was derived has not been produced by crossing and selection. We therefore have through hybridization and segregation no experimental demonstration of the origin of a race of plants so different from those from which it comes that it could not by hybridization once more be merged with the original types. In addition the problem of adaptations is untouched by this explanation.

So many different things are called evolution that extreme care must be used to determine just what anyone means when he says evolution. Darwin's *Theory of Evolution* and Lamarck's *Theory of Evolution* are something more than evolution. They represent attempts, admittedly imperfect, to explain the *method* and *cause* of evolution; evolution itself is the *fact* that the kinds of plants and animals at present existing have been derived by the process of reproduction from somewhat different previously existing kinds. Biologic evolution is a natural law, summarizing certain facts in the same sense that the law of gravity summarizes the behavior of falling bodies and the movements of planets. Such natural laws are our incomplete and imperfect attempts to describe the things which happen.

CHAPTER XXVII

The Distribution of Plants on the Earth

The study of even a few representatives of the great groups of plants reveals something of the great variety of the plants which cover the earth. Several hundreds of thousands of species are known and named, and probably many more are yet undiscovered; to say nothing of the varieties into which many of the species are subdivided. Furthermore, as we have seen, in this profusion of plant life there are many and striking differences between the species; in external appearance, in internal structure, and in physiological reactions. If we compare a cactus with an elm, a violet with a mushroom, a fern with a bacterium, we are impressed by the enormous variety of different structures and functions among different plants and groups of plants.

250. The Variety of Plants and of Environments.—This enormous wealth of plants of almost every conceivable form is spread over almost the whole of the earth's surface. Only a few places, such as the tops of high mountains and extremely arid deserts, are without plant life. But different parts of the earth differ greatly in the species of plants which they support. No one place is inhabited by all kinds of plants, and many places have only a few kinds. It is common knowledge, for instance, that there is a tremendous profusion of plants of many species in a tropical forest, while in the great dry plains of the western United States the vegetation is much scantier and comprises entirely different species.

This distribution of plants is not haphazard. Many of the peculiarities which distinguish one species from another are so important in the life of the plants that they restrict them to certain kinds of environments, or at least render them better fitted to some environments than to others. This is not true of all species. Certain common plants, such as the dandelion, can flourish in a wide variety of environments. But a water-lily or a bulrush cannot live and thrive except where water is very abundant—in a pond or marsh; while a cactus is fitted to live in very arid regions, where other plants cannot survive, and it cannot compete in moister regions with the kinds of plants that naturally grow there.

Similarly we find plants particularly suited for life on high mountains, on bare rock cliffs, in bogs, in regions of very high and of very low rainfall. The existence of a certain species in a certain place is determined by the characteristics of the species in question (its inheritance) and by the climate and soil and other organisms of that place (the environment). The study of plants in relation to their environments is called *Ecology;* the study of the distribution of plants over the earth is known as *Plant Geography*. These two subjects are interrelated; the distribution of any species over the earth is dependent upon its adaptations to the various sorts of environments present on the earth. The following pages treat of some of the more important environmental factors, which differ greatly in different places, and of some of the more striking results of these differences.

251. **Water as an Environmental Factor.**—The importance of water in the life of a plant has already been discussed. All living plants, if they are to continue to live and reproduce, must have a supply of water at least at some time during their life cycles. But plants differ greatly in the amounts of water which they need and in the amounts which they can endure. Ordinary land plants are protected to a certain degree against excessive transpiration. The layers of cutin or cork on their leaves, stems, and roots, the reactions of their guard cells, and other special characters, prevent them from losing too much water during ordinary conditions of climate. They are not protected sufficiently, however, for life in a desert, where the only water is deep in the soil at least during most of the year, and the air may be extremely hot and dry. Neither are they fitted for life immersed in water, where oxygen and carbon dioxide are relatively less abundant than in the air or in the soil. When a valley is flooded by the building of a dam across a stream the trees and other ordinary land plants are gradually killed by submersion; the projecting dead stumps of the trees bear witness for many years to their lack of adaptations for such conditions.

A cactus or sage-brush plant is much more efficiently protected against transpiration, both by heavy deposits of cutin and by the absence of large transpiring surfaces; and its long roots are able to penetrate to great depths beneath the arid upper layers of the soil. Still other plants, such as *Elodea* and the pondweeds (*Potamogeton*), have no cutin at all, and perish quickly if exposed to

dry air; they can live under water because of their delicate and relatively simple structure (which permits the ready absorption by all cells of water with dissolved gases and nutrients) and because of the air channels which their organs usually contain, in which various gases may be stored or conducted from part to part.

All plants may be grouped roughly into three classes according to their water requirements. These are *Hydrophytes*, which live normally immersed in water, floating on water, or in marshes; *Xerophytes*, which live normally in deserts, on high mountains, or raised off the ground on rocks or on other plants, all of which situations are usually poor in water; and *Mesophytes*, which are suited to conditions intermediate between these two extremes, and include most of the familiar plants of ordinary, well-watered land.

The amount of water present in any place depends upon a variety of factors; primarily, of course, upon the rainfall normal to the region, also upon the soil, which may permit the water to drain away rapidly, as it does in sand, or may hold it near the surface, as clay does. Under certain conditions water may be present in large amounts but not available to the plant. During the winter, for instance, the ground may contain large quantities of water which is frozen and hence incapable of diffusing into plant roots; the snow on the surface is similarly of no use. In certain soils there are such large quantities of dissolved materials that the water cannot diffuse into the cells of most kinds of plants, for in them the concentration of dissolved materials is lower. Such soils are found in the strongly alkaline regions of some of the western United States. Strangely enough, bogs, which are saturated with water, have apparently similar characteristics. When an environment is of such a character that plants cannot obtain abundant water from it although quantities of water are present it is said to be physiologically dry; it is dry as far as living plants are concerned, and many kinds of plants cannot survive the lack of water, just as a man may die of thirst in the middle of the ocean.

252. The Soil.—The nature of the soil is important in many ways besides its effect upon the amount of water available. The acidity or alkalinity of the soil has been shown to be correlated with the species of plants which grow in it. Certain plants, such as the orchids, can grow well only in acid soils; this is true also of mountain-laurels (*Kalmia*), rhododendrons, and blueberries (*Vaccinium*). Other species can flourish best in an alkaline or neutral

soil; examples are sweet clover (*Melilotus*) and cliff ferns (*Pellaea*, etc.). The vegetation is affected also by the stability of the soil. Sandy soils are frequently very easily moved by the wind, swept up into gradually shifting dunes. In such soil many plants become buried and killed; certain grasses, however, form such tangles of fibrous roots that they are able to "bind" the shifting sand and continue to live there. In regions of heavy rainfall the soil, together with many of the plants in it, is apt to be carried away by erosion. A familiar example of this is seen also along streams; the current

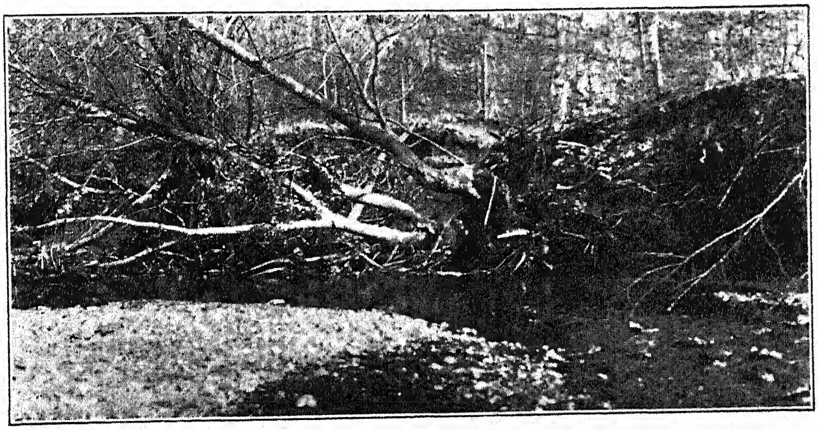


FIG. 366. The influence of a stream upon the vegetation of its banks. During the high water of spring, the stream carried off so much soil that the trees were undermined and fell toward the water.

gnaws continually at the banks and carries away the soil; the trees rooted in this soil are undermined, lean towards the stream, and finally fall. The nutrients in the soil are of primary importance to plants. A few species are able to grow in soils extremely poor in mineral nutrients (for instance sands); leguminous plants, if infected with nodule-forming bacteria, can flourish in soils poor in available nitrogen; soils containing an abundance of humus and inorganic substances are able to support a much larger variety of plants.

253. **Light, Wind, and Temperature.**—The importance of light has been already emphasized. It takes part in photosynthesis, and is concerned in many other reactions of the plant. Species differ in the amounts of light which they need and which they can

tolerate. Direct sunlight of high intensity is injurious to protoplasm and kills some kinds of plants, for instance such algae as *Protococcus;* other plants are protected by hairs or by layers of

FIG. 367. Plants shaped by the wind. Monterey cypress on the California coast. Very little wind was blowing at the time the photograph was taken, the shape of the trees being a permanent response to the prevailing winds from the ocean.

cutin or other substances from the injurious rays. The velocity of the wind is concerned in the rate of transpiration, and so has a profound effect upon plants. In regions of strong and frequent winds, such as the slopes of high mountains, the only plants that can long survive are those that are well protected (by cutin or hairs) from transpiration or are so low and close to the ground that they are not exposed to the full force of the wind. Besides its effect upon the water content of a plant, wind may also shape the plant and govern the direction of its growth. On high mountains and on certain sea-coasts the winds often blow persistently and violently from one direction during long periods; the plants which grow there, especially the trees, are frequently one-sided, stunted, and misshapen, and may grow obliquely along the ground instead of straight upwards. Temperature controls the rates of many chemical reactions, and so controls life processes to a certain degree. This has been already illustrated by the variations in the rate of protoplasmic streaming in an *Elodea* leaf. Only great extremes of temperature can destroy all life in most kinds of plants; but low temperatures reduce the rate of growth, higher temperatures accelerate it (provided other factors are favorable). In temperate

climates, for instance, almost all growth ceases during the coldest months of the year (see the frontispiece).

254. **Other Organisms.**—The life of a plant is affected also by the other plants and by the animals (including man) with which it

FIG. 368. Stunted trees (mostly *Pinus albicaulis*) near the upper limits of tree growth on Mount Rainier; about 6000 feet above sea level. The larger trees are many years old; their one-sided form is a permanent distortion, for little wind was blowing at the time the photograph was taken.

may be associated. A shelf fungus may weaken and kill a forest tree (see Fig. 168). A strangling fig or a grapevine may compete for light and for nutrients in the soil with the plant which it uses as support, at the same time greatly increasing the strain upon its roots and branches. Some of its neighbors, however, may benefit a plant. The nodule-forming bacteria (Fig. 67) in the roots of a leguminous plant aid in its nutrition. A tree by shedding its leaves enriches the soil with humus which may support mushrooms and various other saprophytes. The fungus and the alga which together compose a lichen are of mutual benefit. And, of course, although we regard the presence of a parasite as injurious to a green plant, the presence of the green plant is a benefit to the parasite. Among the animals, the insects present one of the most serious problems encountered by a plant. The disastrous effects of the visitations of tent-caterpillars, locusts, or leaf-cutting ants are well known. Grazing animals may eat seedlings, gnaw bark from trees, and generally tend to restrict the growth of certain species.

Man, of course, has exerted a tremendous influence upon the vegetation of the earth. Over vast regions he has destroyed the natural vegetation and introduced cultivated crops—wheat, corn, fruit trees, and so on; also, incidentally, certain weeds (such as the pigweed, *Amaranthus*), which are now common pests in places thousands of miles from their original haunts. Over other large areas man has transformed what was an unproductive desert into

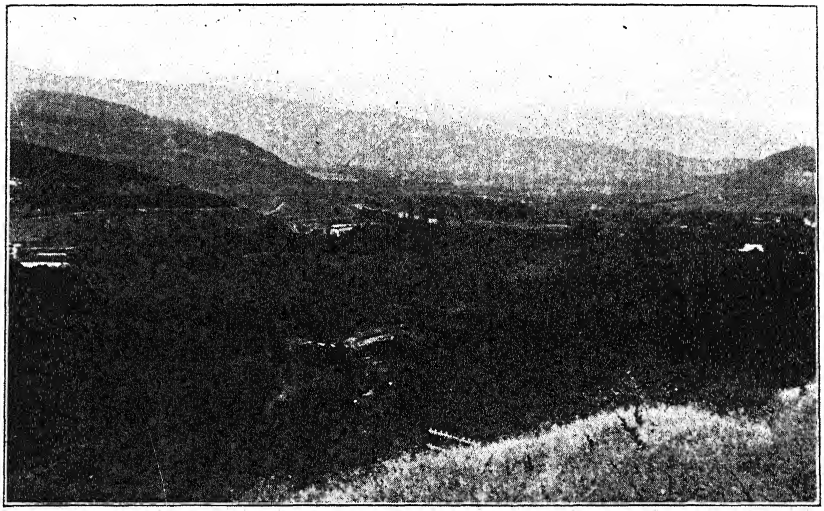


FIG. 369. The effects of irrigation. The Wenatchee valley in central Washington. Contrast the rich cultivated areas (mostly apple orchards) with the desert mountains in the background.

fertile country—he has made the desert "to blossom as the rose." [1] The most familiar examples of this are furnished by the great irrigation projects by which he has penned up streams and diverted their otherwise wasted waters to thousands of square miles of arid country. These activities are, on the whole, constructive. While we occasionally lament the disappearance of the primeval wilderness, we gain thereby our daily bread. Others of man's efforts have been purely destructive in their effect upon the vegetation. He has felled vast forests and by wasteful and ignorant methods neglected to provide for their replanting; with the result that great tracts of land, particularly in the United States, are now

[1] Isaiah 35, 1.

barren or else are producing useless plants instead of the great trees which formerly covered them. Man's carelessness is often responsible for the forest fires which annually ravage some of his most valuable possessions.

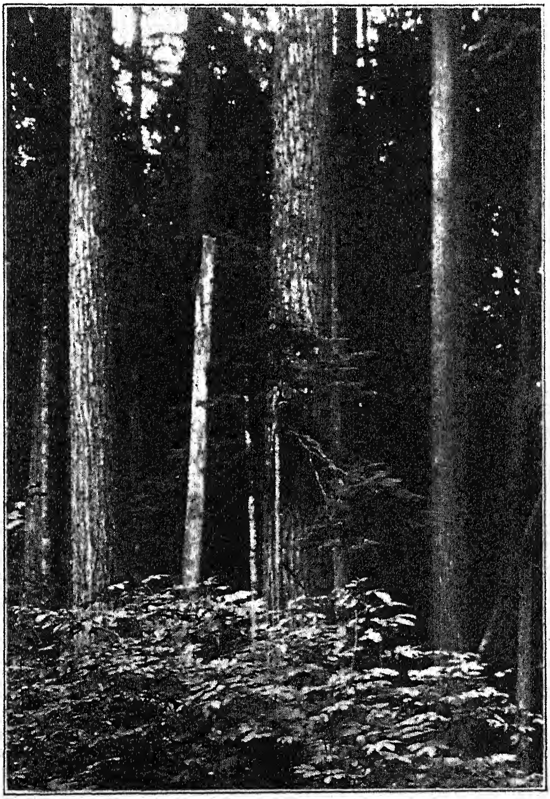


FIG. 370. A portion of a coniferous forest (composed mostly of Douglas fir, *Pseudotsuga taxifolia*) in western Washington. The broad-leafed shrubs in the foreground form the present margin of the forest.

255. Plant Associations.—As a result of all these factors, any one spot on the earth is adapted for the growth there of certain species of plants. No one factor determines the kinds of plants which can grow there, but the whole complex environment. In any particular place, therefore, we find certain species growing, these species being suited by their hereditary characteristics for

such an environment, and being also such as can live together without mutual destruction. If we compare places differing in climate and in soil, we find entirely different kinds of vegetation. On the dry, windy plains of western Kansas, for instance, we find many sorts of grasses, lupines, the loco-weed and other species of *Astragalus*, soapweed (*Yucca*), a few kinds of xerophytic shrubs such as sage-brush (*Artemisia*), and very few trees, except along streams. A few hundred miles farther west, in the Rocky Mountains, we find rocky valleys whose sides are clothed with coniferous trees—pines, firs, and spruces—and with many bright-flowered

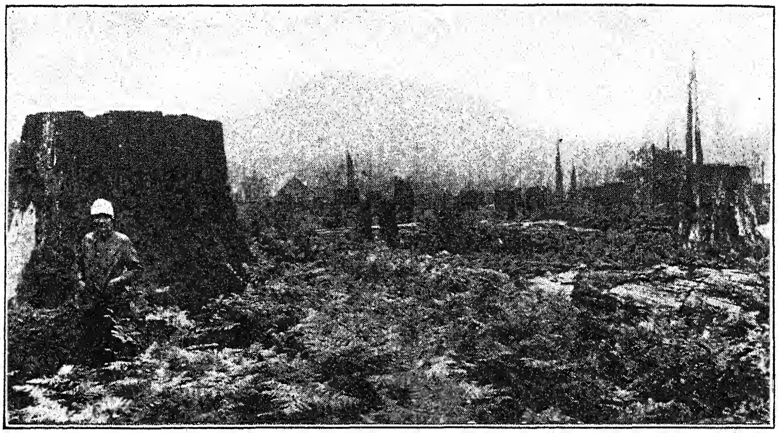


Fig. 371. A lumbered area in western Washington, once covered by a forest like that shown in Fig. 370. Notice the growth of ferns and broad-leafed shrubs instead of conifers.

herbs and shrubs, such as columbines (*Aquilegia*), painted-cups (*Castilleia*), larkspurs (*Delphinium*), bluebells (*Mertensia*), shooting-stars (*Dodecatheon*), and wild roses.

It is evident that for any given environment various species may be fitted. In one stream valley we may find such various plants as willows, sycamores, elms, violets, sunflowers, asters, cocklebures, and a host of others. These all differ among themselves in their peculiar means of adaptation, but are all adapted to the same general locality. Furthermore, all parts of any one locality are usually not the same in their influences on plant life. This is due partly to the topography, and partly to the plants themselves. In a forest the plants of the forest floor may be heavily shaded

by the trees and surrounded by humid air, while the tree tops are in brilliant light and air of low humidity, connected only by their long stems and roots with the source of water. Epiphytes growing

FIG. 372. A portion of a forest association in northwestern Oregon. Notice the masses of moss epiphytic upon the birch trees; ferns also are conspicuous. The photograph was taken near a stream in the midst of a mixed coniferous and deciduous forest.

upon the limbs of the trees have no direct connection with the water of the soil and may be exposed to considerable drying. Where streams flow, their rocky beds may be dripping with water and covered by moisture-loving mosses, ferns, and liverworts. The environment varies also with the seasons. In temperate countries the winter puts an end to growth, and various species

are enabled to remain alive by shedding their leaves or by the death of aërial parts. In early spring many low flowering herbs can take advantage of the lack of shade for a brief growing season. All this complex group of environments, supporting perhaps hundreds of species, is determined partly by the soil and climate common to all of them, partly by the principal species which grow there—particularly trees. Such a complex group of plants existing together and partially dependent upon one another and upon the dominant species is called a *plant association*. It in turn may be divided into smaller plant communities, according to differences in conditions (and consequently in species) within the association.

256. **Plant Invasion and Succession.**—If there are (as there must have been everywhere in times past) areas upon which no plants are growing, but which are suitable for the growth of at least some species, they will become invaded by such species as are adapted to that environment. Seeds are carried through the air or by animals, spores drift on currents of air or water, and from these young plants make their appearance. On a dry, exposed area, such as an exposed face of rock, the only successful plant invaders will be such plants as lichens (see Fig. 206); if the rock is at least sometimes wet, perhaps mosses and liverworts may gain a foothold (see Fig. 244a). As these plants grow and absorb from the rock certain of its minerals, the rock changes in texture, and may become less hard. Some of the plants, or parts of them, die, and their bodies provide a substrate for the bacteria which cause decay. The disintegrated remains of dead lichens or mosses accumulate in the crevices of the rock, and gradually a layer of soil develops. The soil may be able to retain some of the water, or to absorb it from lower levels by capillary action, so that now the area is capable of supporting plants less xerophytic in character, and seeds may germinate and grow into mature plants—perhaps various herbs. As the same processes continue, trees may successfully invade the area. By this time, the location is no longer suitable for the first colonizers, and many of them may disappear. The succeeding kinds of plants themselves produce changes in the environment, enriching the soil with humus (particularly by the shedding of their leaves), creating by their shade a humid layer near the soil, and so on, until we have such a complex situation as that which is described in the preceding paragraph, supporting a plant association. Such a sequence of events, one species or

group of species preparing the ground for another and itself perhaps disappearing, is known as a *plant succession*. The succession proceeds in an orderly way. The kinds of plants at each stage are determined by the nature of the original substrate, by the climate, by the kinds of plants which have already made their appearance. They are determined also by the topography of the surrounding regions. Spores and seeds may migrate by many agencies to new regions, but often cannot cross mountain ranges or traverse wide oceans. Isolated regions are apt to be invaded by fewer species than easily accessible regions (these few species may, however, evolve into a great number of new ones). Finally a type of association is reached which does not produce any further changes in the environment (provided no changes occur in climate or in soil), and which therefore perpetuates itself instead of yielding

FIG. 373. The end of a lake. The dark patch in the foreground is composed of mosses (*Sphagnum*), soaked with water and partially floating on hidden water. The size of the original lake, most of which is now dry, may be guessed from the surrounding topography. This land has been lumbered; notice the growth of poplars and other small trees which has largely replaced the original conifers.

to new types. Such a group of plants is known as the *climax association*. Many of the great forests of the United States are climax associations.

If the original area is one abundant in water, perhaps a pond,

the first plants will of course be of an entirely different character. Algae, certain water-loving seed plants and some kinds of mosses and fungi can flourish in such an environment. But as the decomposed or partially decomposed remains of such plants (particularly of certain mosses, the peat mosses) accumulate, the pond becomes filled up and becomes a swamp, marsh, or bog. This provides a suitable substrate for still other sorts of plants—rushes or cranberries or heather; the watery environment may gradually become solid land, inhabited by some sort of forest. The final result is quite apt to be the same as the climax association upon what was originally a dry rocky area. In general, associations progress from extremely hydrophytic and xerophytic toward mesophytic conditions.

A mountain or a valley may support several different associations, and a discussion of all the associations of such situations would necessarily be long and detailed. However, most of the associations of any one kind of topographic formation have certain things in common. For the purposes of a general survey of plant associations and their distribution over the earth (Plant Geography), therefore, it is sufficient to consider certain general types of associations, such as coniferous forests, grasslands, and so forth. Such types of vegetation are, of course, frequently not sharply delimited from each other; coniferous trees are often found in a forest whose prevailing character is deciduous, and *vice versa*. The following paragraphs describe some of the more familiar types of vegetation, without any attempt at an accurate and detailed classification of plant associations.

257. **Coniferous Forests.**—On high mountain ranges almost everywhere on the earth we find forests of coniferous trees, classed as Gymnosperms. These trees in general exhibit a xerophytic type of structure, which suits them to the rather rigorous conditions found on mountains, where the growing season is short, the winds high, the air dry, and the winter long and severe. The species which compose the forests vary greatly with different localities. In the Rocky Mountains there are communities of various spruces (*Picea*) and pines (*Pinus*). In the Sierra Nevada of California the dominant trees are yellow pines (*Pinus ponderosa*), incense cedars (*Libocedrus*), and western hemlocks (*Tsuga*), with occasional groves of giant redwoods (*Sequoia*). Farther north we find the Douglas

fir (*Pseudotsuga*) associated with pines and hemlock. In many parts of Europe the Scotch pine (*Pinus silvestris*) and various spruces and firs (*Abies*) cover the mountain ranges. There are coniferous forests also in China and Japan. There are other regions, not mountainous, where the conifers dominate. The northern parts of Wisconsin and Michigan, for instance, where the soil is apt to be sandy and the winters long, are (or were) covered with great forests of white and Norway pines (*Pinus Strobus* and *Pinus resinosa*), mixed with various other species belonging to all groups of plants. In the Southern states there are forests of the long-leafed pine (*Pinus palustris*), and swampy areas covered with bald cypress (*Taxodium*). Mingled with coniferous trees we find often such plants as birches (*Betula*) and other deciduous trees, *Lycopodium* and *Selaginella*, and an abundance of mosses.

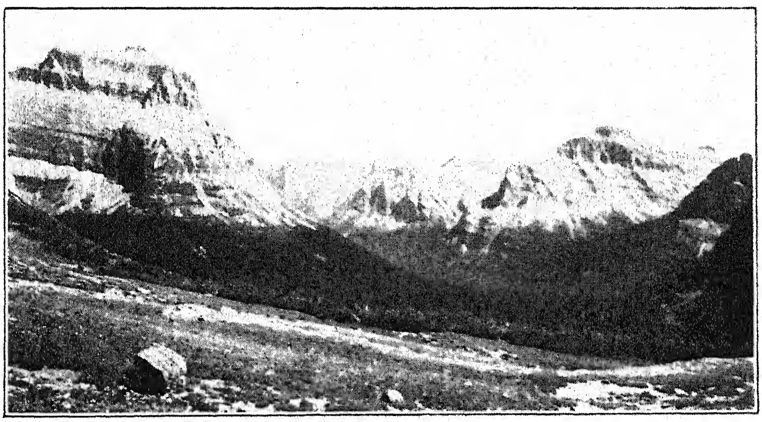


FIG. 374. The timberline in the Rocky Mountains (Glacier National Park, Montana). The valley is filled with large coniferous trees which end rather abruptly at about 6000 feet above sea level. The camera was standing at a point about 6500 feet above sea level.

The coniferous forests have perhaps suffered most at the hands of man. The regular stands of straight, tall trunks make good lumber relatively easy to obtain in large quantities. Many of our finest forests have disappeared bodily before axe and saw and the accompanying fires. The unfortunate feature of their disappearance is that they are usually not replaced immediately by young trees of the same type. Their removal so changes the

environment that it is suitable only for poplars, birches, wild raspberries, ferns, or other comparatively useless types of plants.

258. Plants of Mountains.—As we ascend a high mountain, we pass the so-called "timberline" above which trees cannot grow. The level of the timberline varies in different mountain ranges, being about 6,000 feet above sea level in Oregon and Washington, but as much as 11,000 feet in Colorado. Above the timberline there may be several thousand feet of vegetation, some of it extraordinarily rich, but dwindling as we ascend to regions of greater cold, shorter growing season, and more intense winds. Near the timberline, especially on mountains which are perpetually snow-capped, we may find luxuriant meadows watered from the ever-lasting snows above and displaying during their brief growing season of about three months or less an extraordinary and beautiful profusion of brilliant flowering plants. The slopes of Mount

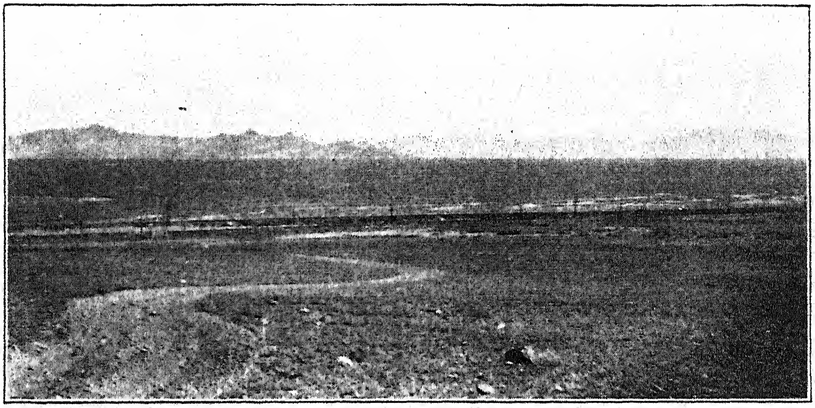


FIG. 375. The Great Salt Lake desert. In the foreground is a region covered with small grasses, sage, and other xerophytes. The desert in the distance, and the mountains, are almost without plant life. The white streaks beyond the railroad are patches of "alkali."

Rainier and of many others of our western mountains are well known as marvelous wild gardens, glowing with the rich colors of blue lupine, red painted-cup, white valerian (*Valeriana*), yellow and pink monkey-flowers (*Mimulus*), blue and red *Pentstemons*, white avalanche lilies (*Erythronium*), red and white heather (*Phyllodoce* and *Cassiope*), and many other species. Higher up we come to rockier, drier regions, and finally to those levels which are

covered by snow and ice even through the summer; in mountains which are not snow-capped, moisture may be very scanty above timberline and on their barren tops. In such places a few stunted plants eke out an existence—dwarf lupine, dwarf phlox, *Eriogonum*, pussy-paws (*Spraguea*); and lichens flat against the rocks. These plants are xerophytic. They possess small thick leaves which store water and are protected from transpiration, or narrow, needle-like leaves which have very little transpiring surface. They have deep roots, and short stems which often bear the leaves close to the ground in a rosette, such an arrangement protecting them from too much exposure to the drying effects of the winds.

259. **Plants of Deserts.**—A few parts of the earth are so lacking in water that they can support no plant life. Parts of the Sahara

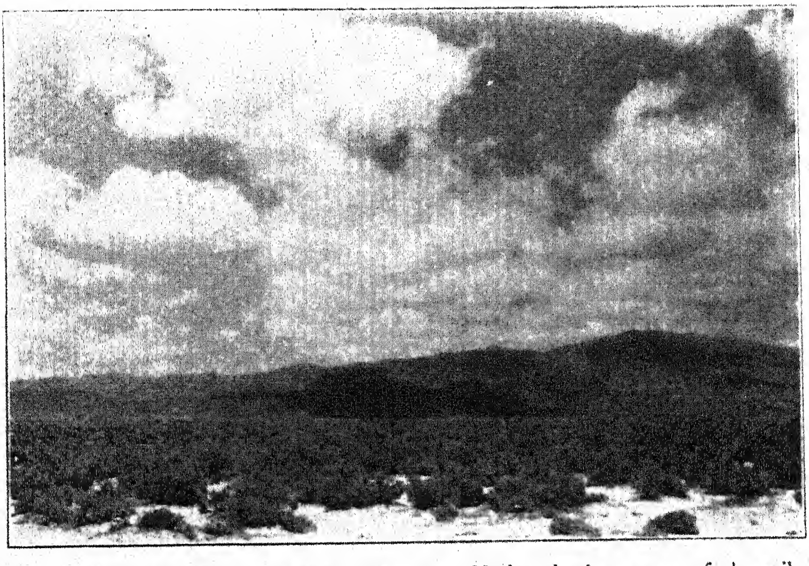


FIG. 376. The sage-brush desert in Nevada. Notice the barrenness of the soil between the sage bushes.

in northern Africa, of Mongolia, and of the deserts of the south-western United States are of this type. Other factors, however, besides lack of rainfall, may contribute to the barrenness of a place. The great Salt Lake Desert of Utah is barren, not primarily because of lack of water—there is sometimes standing water on it in places, and its soil is at times of a pasty moist consistency—but because of

the high concentration of certain salts, the so-called "alkali," which may be so abundant as to form a white scum over the surface. Sandy regions are frequently barren because, in addition to letting the water drain away rather rapidly, they shift so easily with the winds that most sorts of plants find it difficult to obtain a foothold; or, if they become anchored, may be buried by the sweeping dunes. In many so-called deserts, however, there is a scattering of plant life of certain very xerophytic types. Large parts of our western states, for instance, are very dry during the summer, and in many places covered with alkali; but certain plants, such as the sage-

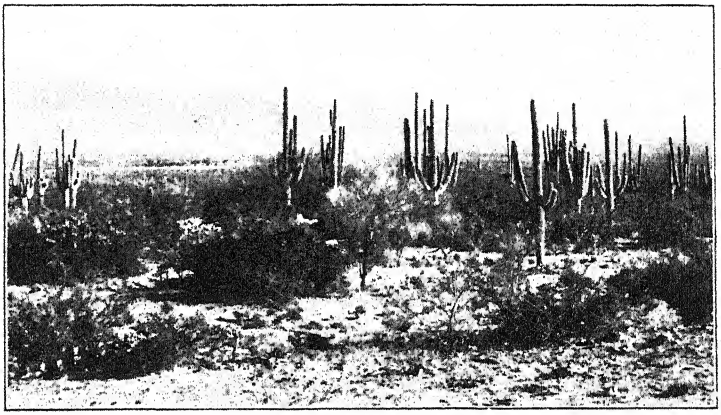


Fig. 377. The desert in Arizona. Giant cacti are conspicuous. (Courtesy of Forrest M. Shreve.)

brush, greasewood, and some cacti, can exist under such conditions. In the southwest the cacti and certain tree-like *Yuccas* (related to the lilies) assume giant sizes and fantastic shapes. In the deserts of Africa the place of the cacti is taken by members of another family of plants, the *Euphorbias*, which have similar peculiarities—few leaves, many spines, enlarged fleshy stems. The south African veldt is mainly very dry, and is inhabited by certain grasses and various thorny trees, such as species of *Acacia*. There are similar regions in northern and eastern Asia. Regions of this type, dry but inhabited by scattered xerophytic plants, are often known as steppes.

260. Plants of Prairies and Grasslands.—As one travels from west to east in the United States, one traverses regions of increasing

rainfall, and the landscape changes from a sage-brush desert to a grass-covered prairie. Here the soil is fertile and rainfall fairly abundant, but there are frequently prolonged dry periods. Why these great expanses should not support forests is still a matter for discussion. Many species of grasses flourish, and, among the

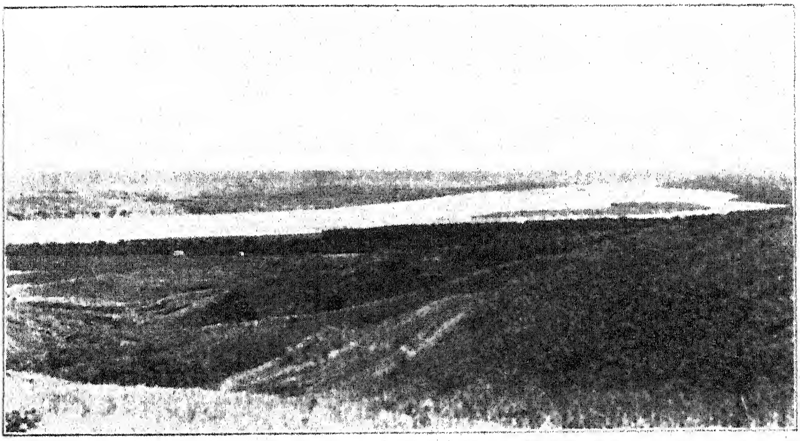


FIG. 378. The prairies of South Dakota. Grasses are the dominant vegetation. Notice the trees which border the stream (the Missouri River).

grasses, many flowering herbs. Along the streams grow willows and cottonwoods. To the eastward the prairie merges gradually into the great deciduous forest which once covered the eastern part of the United States. The transition is very gradual, and there are numerous meadows alternating with forested regions. There is no very sharp line between prairies and meadows on the one hand and prairies and desert on the other. Grasslands occur also in other countries. In the tropics they are known as savannahs; in South America as pampas.

261. Deciduous Forests.—Many of the great agricultural states of today once supported a vast forest of deciduous Angiosperm trees, associated with herbs, mosses, ferns, and sometimes conifers. Most of the trees have been destroyed to make way for the cultivated crops, but isolated groups of them stand everywhere, adding both beauty and shade to pasture and yard. Such forests are associated with regions of abundant rainfall, and with a regular alternation of cold and warm seasons. Many kinds of plant

associations are included, which depend upon the soil and climate of particular localities. In regions unsuited for intensive agriculture, certain associations still maintain their sway—for example the oak and hickory association of the Missouri Ozarks, and the

FIG. 379. A portion of a deciduous forest in Missouri. The principal trees are oaks and hickory. The opening in the center is due to a stream. (See also the frontispiece.)

beech association of southern Indiana. Extensive deciduous forests occupied also most of Europe.

262. Plants of the Tropics.—In the tropics there is no marked alternation of warm and cold seasons. There may, however, be an alternation of wet and dry seasons, and many of the species that grow there shed their leaves in the dry season just as those of temperate regions do in winter. The advantage, of course, is the same in both climates. In general, in the tropics, the temperature is so much more uniform and water so abundant that hundreds of species grow in widespread abundance and reach sizes astonishing to the native of temperate zones. The rapidity of growth of the bamboo has already been mentioned. In Jamaica there is a bean (*Entada*) the pod of which reaches a size of three or four feet in length and contains seeds two or three inches in diameter; its

Fig. 380. The tropical rain-forest in the Amazon valley, seen from the air. The clearing and the native dwelling serve to give an idea of the size of the trees. (Copyright National Geographic Society. Reprinted by special permission from the National Geographic Magazine and by courtesy of Hamilton Rice.)

stem may be a mile in length, creeping along the ground (these plants are said by the natives to start in the mountains and to continue growing until they reach the sea). In the same country huckleberries grow on trees (*Vaccinium meridionale*) forty feet high and eighteen inches through the trunk, instead of upon low bushes. Among the plants native to the tropics mankind has found many of his most valuable foods, spices, and beverages; for example, cocoanuts, bananas, pineapples, cinnamon, nutmeg, ginger, coffee, cocoa, and many others; also the species which yield the rubber of commerce. In many parts of the tropics, for example the vast valleys of the Amazon and its tributaries, large parts of India and Africa, and the Malay peninsula, the rainfall is very great, the soil very rich, and an almost impenetrable "jungle" covers the earth. This is often called the "tropical rain-forest." It is made up of

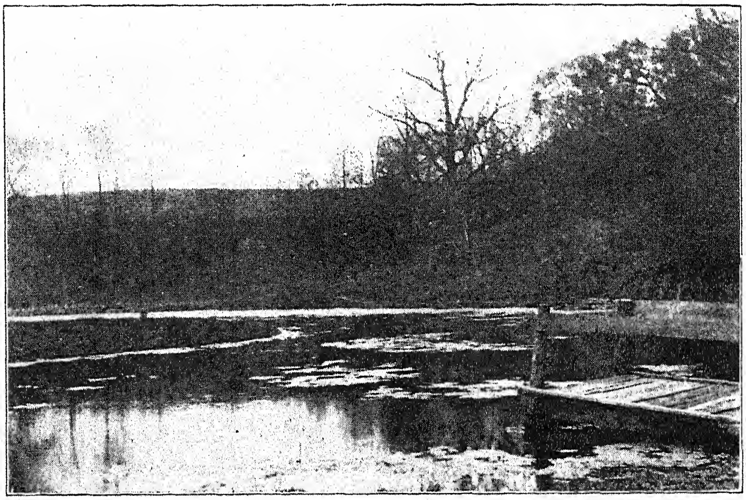


FIG. 381. Masses of algae floating upon the surface of a pond in Missouri.

giant trees towering hundreds of feet up to the sunshine, festooned with great lianas, and often bearing huge epiphytic ferns, and orchids with flowers of startling shapes and gorgeous colors; while below exist hundreds of species of moisture-loving and shade-loving shrubs and herbs (see Fig. 227).

263. Plants of Aquatic Environments.—Bodies of water are found in almost all parts of the earth—swift streams, sluggish

rivers, creeks, clear lakes, muddy ponds, oceans. These waters support a vast and interesting array of plant life. Here are found numbers of species of algae, both attached to rocks or to the mud and floating free near the surface. The intricacy and variety of these plants have already been discussed. Besides the algae there are many Angiosperms which are adapted to an aquatic environment —*Elodea*, water lilies (*Castalia*, *Nymphaea*, etc.), rushes (*Scirpus*), pondweeds (*Potamogeton*), arrowleaf (*Sagittaria*), and so on. The kinds of plants present and their abundance depend upon the temperature of the water, the amount of movement of the water, and the degree to which it can be penetrated by light. In mountain lakes, although they are wonderfully clear, there is little or no plant life, because of the low temperature. In many inland lakes

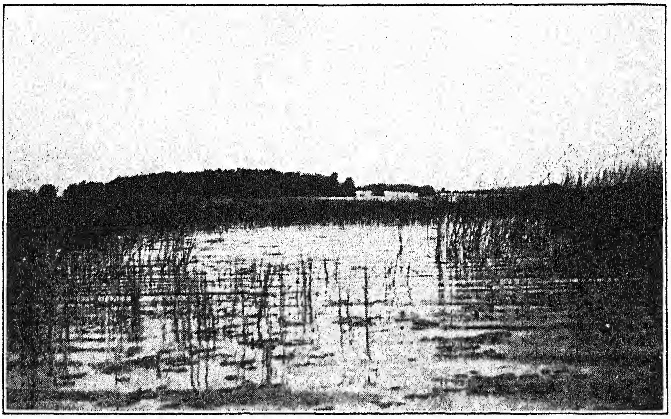


FIG. 382. Aquatic vegetation of Green Lake, Wisconsin. Bulrushes (*Scirpus*) arising from the water, the leaves and flowers of the yellow pond lily (*Nymphaea*) at the surface.

there are such quantities of suspended materials in the water that light is quickly absorbed or reflected, and plants are not found growing in depths greater than about thirty feet below the surface; in such lakes they therefore form a zone around the margins, where they are attached to the slope of the lake floor. In certain ocean waters, however, plants can live several hundred feet beneath the surface. Many species are able to resist the buffeting of ocean waves; *Fucus* and its relatives are some of these. Others cannot stand the waves even of inland lakes, and the more exposed shores of such lakes are frequently almost lacking in attached plants.

Swamps offer a peculiar combination of an aquatic environment with an ordinary environment. Plants that grow in swamps have roots and rhizomes living under water, but bear aërial stems and

FIG. 383. A portion of Reelfoot Lake, Kentucky; a cypress swamp. (Copyright by the National Geographic Society. Reprinted by special permission from the National Geographic Magazine and by courtesy of A. W. Stevens.)

leaves which are subject to much the same conditions as ordinary mesophytes. Some trees, for instance the bald cypress (*Taxodium*), are able to flourish in such conditions. In the temperate countries,

however, swamps are inhabited mostly by herbaceous plants, such as rushes, cat-tails, arrowleaf, and the like. If we study the structure of an ordinary bulrush (*Scirpus*), we find that its stems contain large air-passages, which enable its underwater parts to

FIG. 384. Aquatic vegetation of the Pacific coast, at low tide. Many large algae are visible, the most conspicuous being *Iridia*, a red alga. (See also Fig. 195*a*.)

receive oxygen; its leaves, however, are small or lacking, the stem, which does not expose much surface for transpiration, doing most of the work of photosynthesis; the vertical position and small surface of such a stem guards it from the dangers of too intense illumination; and at the same time permits the light to reach all parts of the plant even if many of them stand in a dense group. Many aquatic plants are of this type. Others have broader leaves which spread out at or near the surface of the water, like the water lilies.

One type of environment which at first sight might be classed as aquatic should really be considered, apparently, among dry environments, the plants which grow in it being largely xerophytic. This is the bog. Here the substrate consists largely of certain mosses and other semi-aquatic plants in a state of partial decomposition and tightly packed together. The structure of this debris enables it to absorb and retain large quantities of water by capillarity. It is thought that the quantities of organic acids and other substances which result from the decay of such plants cause a

very high osmotic concentration of the water, so that other plants have difficulty in obtaining the water; some of the substances formed may, also, be poisonous to other plants. Such bogs are commonly inhabited by acid-loving xerophytic plants, such as heathers (*Erica*, *Calluna*), blueberries and cranberries (*Vaccinium*), mountain laurels (*Kalmia*), and others. As humus accumulates and the substrate becomes more compacted, it may cease to be a bog and become a peat soil. Large deposits of peat occur in various parts of the world; in Europe they are frequently used as fuel, the peat being cut out in rectangular blocks and stacked up to dry. Of a somewhat similar nature are the great moors or heaths which occupy many parts of Europe. The ground is more or less moist, often swampy, the soil peaty, and the vegetation composed of heathers and allied species. The "bonny purple heather" of Scotland is familiar, at least by repute, to everyone; the rugged uplands of that country consist largely of miles upon miles of heath-vegetation.

The above described types of vegetation do not exhaust the subject. They form merely an introduction to the vast subjects of Plant Ecology and Plant Geography. They serve, perhaps, to illustrate the complexity of the environmental factors and the great variety in the results. Every continent, every country, every valley, mountain, plain, or lake supports a vegetation suited to its peculiarities, a vegetation which exists there because of the characteristics which determine its reactions, and which is perhaps slowly changing the environment and opening the field to other types of vegetation, all in an orderly sequence. It is perhaps only when we travel to some new kind of country that we realize any of this; we are apt to take for granted the ordinary plant associations of our everyday surroundings. None the less these also are the complex results of many diverse inheritances and a complex environment; they are dependent upon the various environmental factors discussed above (besides many others) and include representatives probably of all the great groups of plants and of hundreds of families within these groups, differing in many intricacies of structures and functions, but sharing alike the fundamental activities of all life.

QUESTIONS FOR REVIEW AND DISCUSSION

The Fundamental Structure of Plants

1. What are the chief parts of a plant cell? Are all these parts alive? Are all these parts present in all cells?

2. What parts of living plants are composed of cells and their products? What things other than living plants are composed of cells and their products?

3. Is iron composed of cells? Is wood composed of cells? Is a stone composed of cells? Is an apple composed of cells? Are you composed of cells? State the basis for your answers.

4. Distinguish between the following terms: cytoplasm, nucleus, protoplasm, protoplast.

5. Explain the differences between the following: plastid, chromoplast, leucoplast, chloroplast.

6. What is the meaning of the word cell? How did this word come to be used in biology? How is it used in present-day biology? Can you account for the change in its meaning?

7. Why is the cell theory a *theory* and not a *fact?*

8. Why were cells not known to and studied by the ancient Greek scientists?

9. State the complete cell theory as it is understood today. Who is responsible for this theory? Can you suggest any reasons for the fact that the theory was not enunciated once and for all by one man at one time but by several men over a period of about a hundred years? Do you think that it is possible to change or improve upon the cell theory as at present stated?

10. Give the approximate date at which the following men worked and state briefly their contributions to our knowledge of cells: Hooke, Corti, Schleiden, Schwann, Von Mohl, Dujardin, Cohn, Schultze, Huxley.

11. The average diameter of the cells of a white potato is 0.05 mm. If each cell is considered to be cubical in shape, how many cells are there in a piece of potato 8 cm. long, 4 cm. wide, and 4 cm. thick?

12. To what parts of cells are due the green color of a leaf, the purple color of a grape, the orange color of a carrot?

13. Is the presence of a cell wall of any benefit to the contents? Are the cell walls of plants of any use either to plants or to mankind after their contents are dead?

14. Why do we consider the protoplasm "alive," and other parts not "alive"?

15. The following questions about cork were asked by Robert Hooke in 1665: "First I enquir'd why it was so exceeding light a body? Next why Cork is a body so very unapt to seek and drink in water, and consequently preserves itself, floating on top of water, though it be left on it never so long: And thirdly if we enquire why Cork has such a springiness and swelling nature when compress'd?" Can you answer these questions?

16. The diversity of plants is so great that it would seem impossible without a vast knowledge of the different kinds to study what goes on in them. How do we overcome this difficulty in beginning this study?

17. Why do we start our study of Botany by studying cells and the cell theory?

The Absorption of Water and Dissolved Materials

1. What is meant by the "dry weight" of a plant? How much of an average plant is dry weight?

2. Is there any difference between a dormant plant (such as a seed, or a dry but living moss) and an actively growing plant in the amount of water which they use? Can you suggest any advantage of the dormant condition?

3. Name all the reasons you can think of why water is important in the life of plants.

4. What is a chemical reaction?

5. What is desiccation? What effect does it have upon protoplasm?

6. What is plasmolysis? What is turgor?

7. A sac made of an elastic membrane permeable to sugar and water but impermeable to salt is filled with

(*a*) a 5% salt solution and placed in water;
(*b*) water and placed in a 5% salt solution;
(*c*) a 2% sugar solution and placed in water;
(*d*) a 3% sugar solution and placed in a 2% salt solution;
(*e*) 10% sugar and 2% salt solution and placed in 1% sugar and 1% salt solution.

What happens in each of these cases? Explain why.

8. What is the difference between diffusion and osmosis? What is the difference between diffusion and imbibition?

9. Explain why it is incorrect, in speaking of a cell undergoing plasmolysis, to say that salt solution *draws* the water out of the cell.

10. What is a *concentrated* solution of a dissolved substance? What is a *dense* solution? What is a *strong* solution? What is a *thick* solution?

11. Is it possible for osmosis to occur without the development of osmotic pressure? Explain. State all the conditions necessary for the development of osmotic pressure.

12. State some of the phenomena in living plants not yet explained by diffusion, osmosis and imbibition.

13. With what do the laws of physics and chemistry primarily deal? Why should they be called upon to explain what happens in living things? What other sorts of laws do you think might be substituted?

14. Give a definite example of the usefulness of the cell theory in studying what happens in living plants.

15. Where is the semipermeable membrane in a cell? How could you demonstrate whether a membrane is permeable or semipermeable?

16. Under what conditions do you think that a dissolved substance might diffuse through a membrane and create osmotic pressure?

17. When a colored plant part, such as a beet, is placed in water, what prevents the color from diffusing out? Why does the color come out when the water is boiled?

18. Why does salt water cause thirst?

19. Can you suggest any reason why fruit jellies containing very high concentrations of sugar and other dissolved materials are not decomposed by the bacteria which cause ordinary decomposition of foods? (Bacteria are microscopic living plants, and decomposition depends upon their life and growth.)

20. A typical *Elodea* leaf cell is a rectangular box about 0.4 mm. long, 0.06 mm. wide, and 0.04 mm. deep. The thickness of the wall is 0.004 mm., which is much thinner than the thinnest tissue paper. When *Elodea* is immersed in water, the pressure in the cell is about 55 lbs. per sq. inch. Why does this pressure not burst the cell?

21. What is hydrostatic pressure? What is gelatin? What are

convection currents? What is a liquid? A gas? A solid? A solution? Give examples of the last four.

22. A cell is plasmolysed in a 5% salt solution. What comes out of the protoplast? What goes in? What fills the space between the cell wall and the plasmolysed protoplast?

The Root

1. The first part of a seed to emerge when the seed germinates is the young root. Is this of any particular advantage to the young plant?

2. What happens to a plant when its root system is insufficient to anchor it in the ground? Can you supply any evidence from your own observation?

3. Why does soil not cling to the extreme tip of a root so readily as it does a little farther up?

4. Can you suggest one reason why mesquite is able to live in semi-desert country, where the soil may contain almost no water near the surface, while a corn plant cannot?

5. What is the difference between a branch root and a root hair?

6. Is a root composed of cells? Is a root hair composed of cells?

7. What is the force which causes water to pass into roots?

8. What is an organ? A tissue?

9. Can you think of any reasons why water passes up in the xylem more readily than in other tissues?

10. What is the chief advantage of the possession of root hairs?

11. Whereabouts do branch roots originate? What must they penetrate before they establish contact with the soil?

12. What do you understand by the word adaptation?

13. Explain in detail how the cell theory helps our understanding of the functions of a root. Give definite examples.

14. Why is it more valuable to study a cross section of a root rather than a longitudinal section? Why should we endeavor to study both?

15. Of what advantage is a root cap? Assuming that plant parts usually have those structures best fitted for their functions, would you expect to find such a cap on the tip of a stem?

16. Does the root hair zone get longer as the root gets longer? Explain.

17. If in transplanting a plant one removes all the soil from its roots, it usually dies. Why?

The Stem

1. Enumerate the important functions of a stem. What is a function? What is the difference between a special function and a general function?

2. Name in order all the kinds of cells through which a drop of water passes in its journey from the soil to the top of the stem of a plant.

3. Name as many stems as you can which contain stored food.

4. We call a tuber of a white potato a stem, though it grows underground like a root. Can you suggest any reason why we do so?

5. Enumerate the differences between a young dicotyledonous stem and a young root

    (*a*) in general plan;
    (*b*) in the character of the epidermis of the young portions;
    (*c*) in the arrangement of the parts within the stele.

6. Name five plants with herbaceous stems, five with woody stems.

7. Compare the pericycle of a sunflower stem with that of a buttercup root.

8. What is the difference between a trachea and a tracheid? What is a xylem element? What is a morphologic unit?

9. Contrast a trachea with a sieve-tube. What is the principal function of each?

10. Is the bark of a tree composed of living or of non-living cells?

11. Name five important members of the grass family. What are some other monocotyledonous families of plants?

12. Contrast a monocotyledonous with a dicotyledonous stem.

13. Name the chief functions of the following and explain how each is suited by its particular *structure* and *position* for the performance of its special function: trachea, support cell, pericycle fiber, epidermal cell, xylem fiber, sieve-tube.

14. What is the advantage to the stem of the position of supporting cells near the outside? Is the root weakened because the supporting cells are in the center? What is the reason these cells are where they are?

15. Criticize or explain the following statement: Xylem vessels grow into long tubes in order that they may conduct water the more easily up the stem. Is the statement true? Is it scientific? If necessary, rewrite the sentence so that it expresses the facts in scientific form.

16. Which cells of a corn stem are the largest in diameter? The longest? The most numerous? The strongest?

17. Name the *kinds of cells* present in the following *regions* of a stem: cortex, pith, pith ray, xylem, phloem.

18. If you were studying a plant organ, how could you distinguish between a parenchyma cell and a support cell? Between a tracheid and a sieve-tube?

19. How does the epidermis of a stem differ from that of a root? Is this of advantage to the plant as a whole?

Photosynthesis, Transpiration, and the Leaf

1. How did sugar, starch, etc., come to be called organic substances? Why is the term no longer a very good one? What is an organism?

2. Construct a table showing and contrasting, as much as possible, the properties of organic and inorganic substances.

3. What is burning?

4. To what class of substances do foods belong?

5. Is plant food different in nature from animal food?

6. In what ways are foods essential to the life of an organism?

7. What effect upon the atmosphere would be produced by the cessation of plant life?

8. Why is *Elodea* rather than such a plant as a geranium used to demonstrate the evolution of gas during photosynthesis?

9. What happens in a chemical reaction? Are any atoms lost or created?

10. What is the difference between an atom and a molecule?

11. Name the pigments usually present in chloroplasts. What other pigments may be present in plant cells, and where?

12. What is a plastid? Name three kinds of plastids. What is the difference between a plastid pigment and a sap pigment?

13. Which class of pigments contributes most to the color of the landscape in summer? Which in autumn?

14. What structure usually holds cells attached to one another? How is the fall of leaves brought about?

15. Is a stoma a cell? Is a hair a cell? Is a plastid a cell?

16. Explain in detail just how carbon dioxide enters plant cells.

17. What disadvantage would result to the plant if it were so constructed that water would not evaporate from it?

18. State some of the suggested benefits which result from

transpiration, and discuss the evidence for or against them. What is your conclusion?

19. What is the force which causes water to move up a stem? How is it possible that water has tensile strength in a stem?

20. When plants are transplanted, some of the leaves are often removed. What is the advantage of this practice?

21. Name the *natural* means by which plants may avoid excessive transpiration.

22. Of what use is a windbreak to a field of plants?

23. In what sense is transpiration "necessary"? In what sense is it an "evil"?

24. What gases enter a green leaf in the sunlight?

25. Many plants which remain alive through the winter shed their leaves. Is this of any advantage to the plants?

26. Celery growers frequently cover the bases of the plants while they are growing. What is the result?

27. How could you determine which rays of light are used in photosynthesis? What makes chlorophyll look green?

28. Why do fishes live better in an aquarium that contains living plants, even if they do not use them for food?

29. Upon what evidence do we base the statement that the transpiration stream does not pull the dissolved materials into the plant?

30. What part does imbibition play in the process of transpiration? What part does diffusion play? What part do air currents play?

31. Comment on the following: "Van Helmont planted a willow, which weighed five pounds, in a pot containing 200 pounds of earth. This he watered for the space of five years, and, at the end of that time, the tree was found to weigh 169¼ pounds, while the earth in which it had stood, being dried as at first, was found to have lost only two ounces. Here then was an increase of 164 pounds and yet the food of the plant had been water only."

Foods

1. What are the chemical elements found in all carbohydrates? In fats? In proteins?

2. What is digestion? In what sense is food eaten by a man still outside his body?

3. Why must food be moved from cell to cell in the plant body?

4. Why is translocation necessary to the growth of the embryo plant in a corn grain? What must precede translocation, and why?

5. What is an enzyme? Name four digestive enzymes, and specify the food which each can digest. Is digestion the function of all enzymes?

6. Digestion is sometimes effected in the laboratory by means of concentrated acids, or dilute acids heated; both of which means would be fatal to living cells. How then is digestion accomplished in a living cell?

7. What is the path of a molecule of glucose from the place where it is manufactured to the place where it is stored as food?

8. If a ring of bark is removed from the stem of a plant, the plant dies. Explain why.

9. Trace the journey of a molecule of water which is absorbed by a root hair and is finally found as part of a starch molecule in the cortex of the root. Name all the kinds of cells traversed and the processes into which the water enters.

10. If it is true that light and chlorophyll are both necessary to the manufacture of starch in plants, how do you account for the presence of starch in a potato, which is not green and is underground?

11. What important element exists in the air as a gas but is of no use to ordinary plants in that form? Why is it needed at all by plants? In what compounds may it enter the plant?

12. Name ten elements used by plants in their life-processes, and specify in what form (whether as an element or in a compound) each enters the plant, and from where.

13. How would it affect the human race if plants did not accumulate food in storage organs? Name four stems, four roots, and four fruits in which stored carbohydrates are found and used by man.

14. Name some plants which contain large quantities of fats or proteins. In what parts of these plants are these foods found?

15. What is the advantage of the agricultural practice of planting a crop of leguminous plants and ploughing it into the soil?

16. Name five kinds of leguminous plants.

17. What information about a substance does its chemical formula give us?

THE RELATION OF LIVING THINGS TO ENERGY

1. If we do not know exactly what energy is, how can we say whether energy is present or not?

2. How can energy be measured?

3. Explain in what sense it is true that the sun runs your watch.

4. In the reaction which occurs during respiration, are any atoms lost or created? Is any energy destroyed or created? What is meant by the dissipation of energy?

5. What becomes of the energy liberated in respiration?

6. Distinguish between respiration and digestion.

7. Do plants breathe? Explain.

8. State the law of conservation of energy. What is meant by unavailable energy? Give examples.

9. What is the chief difference between burning and the respiration of living organisms?

10. How could you test for the presence or absence of oxygen? For the presence or absence of carbon dioxide?

11. Why are experiments dealing with respiration commonly performed with germinating seeds rather than leaves or whole mature green plants?

12. Explain the meaning of the terms aërobic and anaërobic.

13. What (if any) is the benefit to the plant of photosynthesis; of transpiration; of respiration; of digestion?

14. Give six examples familiar in everyday life of the transformation of energy.

15. Are all foods organic substances? Are all organic substances foods?

16. Can all organisms use the same foods? How do you account for the fact that certain organisms (fungi) are able to use wood as food while we cannot?

17. Explain the statement that coal contains "bottled sunlight."

18. If the source of the energy by which plants live is sunlight, how do they remain alive at night?

19. Explain how man uses sources of energy different from those used by other organisms.

20. Outline some of the results which would occur if the energy contained in coal and petroleum were no longer available.

21. If two corn grains are planted under exactly similar conditions except that one is in the light and the other in the dark, and allowed to grow for a few weeks; if then the plants are dried

and their dry weights compared with the dry weights of grains similar to those from which they grew; it is found that the dry weight of the plant grown in the light greatly exceeds the dry weight of the grain, while that of the plant grown in the dark is less than that of the grain. Can you account for these facts?

22. Explain exactly how oxygen enters living cells. How does oxygen reach cells in the interior of plant tissues?

23. Name six types of energy. Which of these are used by plants in the manufacture of food?

24. What gases enter and leave a green leaf in the light? A green leaf in the dark? A root in the light? A root in the dark?

25. A man eats 200 grams of sugar, 50 grams of fat, and 200 grams of protein. What becomes of the energy stored in this food? What becomes of the food itself? What becomes of the energy and of the food if the food is consumed by a growing boy?

26. Criticize the statement that respiration is the use of oxygen and the evolution of carbon dioxide?

27. What leads us to believe that in a living organism there occurs a process similar to burning?

28. When and where does respiration occur in a plant?

29. Why must a corn plant be supplied with gaseous oxygen if it is to continue to live? Could oxygen in the form of a component of water (H_2O) replace the gaseous oxygen, the latter being withheld, without detrimental effects?

The Formation of New Cells

1. From what are new cells formed?

2. In what sense is a cell "resting"?

3. Was our present knowledge of the formation of new cells incorporated in the cell theory of the early nineteenth century? Why?

4. What is the meaning of the word mitosis?

5. Of what substances are chromosomes formed?

6. What is our reason for considering the chromosomes to have definite and permanent identities, although they are not visible between divisions?

7. What is the mechanism that, during division, actually separates the visible nuclear material into two groups?

8. Are the chromosomes rigid or flexible? Are they sticky or not? Give the evidence upon which you base your answers.

9. What is the difference between a cell plate and a cell wall?

10. Are chromosomes always formed in mitosis? Is a cell plate always formed?

11. What living parts of the cell are permanent throughout rest and division? What parts are not?

12. What is the difference between equational and reductional division? Which is the more common in ordinary growth?

13. What does a living thing inherit (biologically speaking) from its parent or parents?

14. What is the connection between cell division and inheritance?

15. Is it proper to say that the chromosomes are the bearers of hereditary characters? Explain.

16. What parts of the cell are thought to be most important in its inheritance? Why? Are any living parts of the cell certainly *not* concerned?

17. What parts of a cell are apparently equally distributed between the daughter cells? Are they the same as or different from those which are permanent parts of the cell? Can we attach any significance to these facts?

18. What is an embryonic cell?

19. How does an embryonic cell differ in structure from a mature cell?

20. How many times does the process of mitosis occur in the formation of 100 cells from one original parent cell?

21. Modern methods of killing, sectioning and staining tissues have developed within the last fifty years or thereabouts. Our present conception of the mechanism of heredity is also very recent. Is there any connection between these two facts?

22. Do you think that because mitosis is extremely complex and cannot be duplicated in a laboratory by physical or chemical apparatus it is therefore an example of laws peculiar to living beings, laws which are of a different kind from those of physics and chemistry?

23. Is the cell theory of any use in studying heredity or reproduction? Explain.

Growth

1. In what sense is it possible for a thing to grow without becoming larger?

2. What is one fundamental distinction between the plant and animal kingdoms?

3. What is the difference between the growth of an amoeba and the growth of a slime mold?

4. What is the difference between the growth of a slime mold and the growth of a sunflower plant?

5. What is the origin of the cells which make up a mature plant?

6. Does a cell continue to grow indefinitely? Are there any parts of plants where cells are no longer growing? Are there parts where new cells are continually being formed and are growing? Give examples.

7. Define growth, and illustrate the meaning of your definition by describing the growth of a cambium cell into a trachea.

8. What is the main difference in appearance between a stem tip and a root tip?

9. What is the origin of a leaf? Why do certain embryonic cells become leaves while their neighbors become branches?

10. What is an adventitious bud? A terminal bud? An axillary bud? A vegetative bud?

11. Describe two methods of estimating the age of a branch of a tree.

12. How is the secondary body of a plant situated with reference to the primary body?

13. Explain how it is possible by pruning a fruit tree to obtain a bushier, more symmetrical type of plant.

14. Is a lenticel a hole, like a stoma? Explain how oxygen can enter a tree through a lenticel.

15. What tissues are included under the name bark? How does bark change as it becomes older?

16. If bark is stripped from a tree while it is actively growing, the inner layers are found to be tender and moist—they consist of living cells. What tissues are these?

17. What tissues are included in the wood of a tree?

18. Of what use to a plant are the vascular rays? What is the origin of the vascular rays?

19. Do bud-scales keep the living tissues of the bud warm in winter? Explain thoroughly, showing the advantage of these tightly fitting scales.

20. When an elm bud opens in the spring, either leaves and a new length of stem appear or a cluster of flowers. When was it determined which each bud would form?

21. What is the advantage to the plant of the corky outer layers of a tree-trunk? How does mankind make use of the peculiar properties of these layers?

22. Why is it possible to distinguish the end of one year's growth of wood from the beginning of the next layer laid down the following year?

23. If a tree trunk is encircled tightly by a wire, a swelling appears above the place. Can you suggest a reason for this?

24. In a piece of wood is the grain the same upon two adjacent faces? Explain.

25. Describe how quarter-sawed oak is cut. Why is it expensive? What structures compose the ornamental features of its grain?

26. Does the arrangement of branches of a pine resemble that of an elm? Explain.

27. Can you account for the fact that a sunflower stem or an oak stem tapers from base to top, while a corn stem does not to any appreciable extent? Does the same hold true of roots, and for the same reason?

28. What causes the increase in thickness of a dicotyledonous stem? What causes that of a monocotyledonous stem?

29. What causes the death of the epidermis of a young twig of a tree?

Reactions of Plants

1. Why does a careful housewife turn her potted plants around every few days?

2. Is it reasonable to say that the *absence* of light increases the rate of elongation of cells when we know that the energy used in elongation is derived from light?

3. Make a list of all the effects which you know of light upon a plant.

4. Of what advantage to a plant is it that the main stem is positively phototropic, the main root negatively phototropic?

5. Do any tropisms other than phototropism contribute to the direction of growth of a plant? Do they usually work in harmony with phototropism or against it?

6. How can the force of gravity be practically removed? How can the direction in which it acts on a plant be changed?

7. What is a reaction of a plant? Name ten, other than

tropisms. What is the connection between stimulus and response and the normal reactions occurring in the plant?

8. Why is it necessary to place a plant in the dark when experimenting with geotropism?

9. Why is it best to surround seedlings with moist sawdust when determining the effect upon them of gravity?

10. In what direction and under what conditions does centrifugal force act?

11. How can gravity cause anything (for instance a plant stem) to go upwards?

12. Do all the cells of a plant react in the same way to the same stimulus? Give examples.

13. State the optimum, minimum, and maximum temperatures for streaming of cytoplasm in *Elodea*.

14. What is the most striking difference between plant and animal responses?

15. Is there anything in any plant which you know which corresponds to a sense organ? To a nerve? To a muscle?

16. What do we call the state into which an animal passes when he becomes unable to respond to ordinary stimuli? Is there anything corresponding to this state in plant life?

17. What happens when an organism is unable to respond to any stimuli?

18. In what sense is or is not the closing of a flower at night "sleep"?

19. Why do "all organisms spend all their lives reacting to stimuli"?

20. Do we know that a plant has no consciousness or aims? State just why it is unscientific to speak of the "purpose" of a plant or plant tissue.

Life and Death

1. What is the difficulty in formulating a definition of life?

2. Is there any reason of which we know why living matter cannot be synthesized in a laboratory? Do you think man will ever accomplish this? State your reasons.

3. A few years ago a newspaper article stated that science was unable to give a complete explanation of the absorption of water by a plant and its movement through the plant; and that, therefore, such phenomena are due to vital activities undiscoverable by a

science which limits itself to the natural laws of physics and chemistry. Discuss this point of view.

4. Give an example of a non-living substance which can absorb water by osmosis; a non-living substance which can repair breaks in its body; a non-living substance which can build its body out of a substance different from that of which its body is composed; a non-living substance which liberates energy by which it accomplishes work; a non-living substance which differentiates.

5. In what senses is a living organism comparable to the flame of a gas burner?

6. Which is most true, vitalism or mechanism? Which is most useful? Why?

7. Criticize the statements made in old texts to the effect that the vital principle in an organism is manifested by the ability of that organism to synthesize certain compounds (organic compounds) which man cannot accomplish by ordinary physical and chemical means; also by digestion carried on in living bodies, which man cannot duplicate in his laboratories. What bearing does your criticism have on the status of vitalism?

8. How could you determine if a cell was dead or not?

9. What is a "scientific explanation" of a fact?

10. Can science prove or disprove the existence of supernatural forces, principles, or persons? Explain.

11. Comment on the following statement: "Living things are characterized by the power of movement, growth and reproduction."

12. Huxley said: "Science is, I believe, nothing but *trained and organized common sense*, differing from the latter only as a veteran may differ from a raw recruit." Can you explain just what sort of training is necessary to change "common sense" into science?

The Origin of Life—Spontaneous Generation

1. What explanations have been suggested of the origin of life? Criticize each from the point of view of scientific value.

2. Why was Aristotle a "true scientist," if his beliefs on this subject are now regarded as absurd?

3. What class of organisms did Redi prove not spontaneously generated? What remained to be proven?

4. What revived the theory of abiogenesis near the beginning of the eighteenth century?

5. State the date (approximate), nationality, and occupation

of the following men, and state their beliefs, and the evidence they had in support of them, on the subject of spontaneous generation: Aristotle, Redi, Needham, Spallanzani, Schulze, Schwann, Schroeder, Dusch, Tyndall.

6. From his opponents' point of view, what was wrong with Needham's conclusions?

7. Show how Pasteur and Bastian drew opposite conclusions from the same results. Who was right? How do you know?

8. Comment on the following statement: Spontaneous generation was proved by Pasteur to be impossible.

9. What attitude would you take toward a published article which claimed the creation by its author of living matter (spontaneous generation)?

10. In a mixture of certain organic substances dissolved in water, boiled and then cooled, placed in a tumbler and standing in the sunlight, living cells appeared. Does this prove the origin of living cells from non-living matter? Explain.

11. Comment on the following two quotations:

"When by meditation it became evident to me that spontaneous generation was another one of the means which nature employs for the reproduction of her creatures, I applied myself to discover by what processes one could demonstrate the phenomena." (From the preface of Pouchet's *Treatise on Spontaneous Generation*, 1859.)

". . . On my return home, it occurred to me, in 1837, that something might perhaps be made out on this question (the origin of species) by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it. After five years work I allowed myself to speculate on the subject, and drew up some short notes; these I enlarged in 1844 into a sketch of the conclusions, which then seemed to me probable: from that period to the present day I have steadily pursued the same object." (From the introduction to Darwin's *The Origin of Species by Means of Natural Selection*, 1859.)

12. Comment on the following quotation, and mention a definite example of the sort of thing the author is attacking:

"But the mortellest enemy unto knowledge, and that which hath done the greatest execution unto truth, hath been a peremptory adhesion unto Authority, and especially the establishing of our beliefs upon the dictates of Antiquities. For (as every capacity may observe) most men of Ages present, so supersticiously do look

upon Ages past, that the Authorities of the one excel the reasons of the other." (Sir Thomas Browne.)

Bacteria

1. Give three other names by which the "animalcules" of Leeuwenhoek have been known.

2. What is the usually accepted distinction between plants and animals?

3. What is Brownian movement? Why is it exhibited by bacteria? Who discovered it? For what other biological contribution is he noted?

4. What difference in the life of a plant does the absence of chlorophyll make?

5. How is it possible for bacteria to use as food such materials as wood and leather which other organisms cannot?

6. Why do bacteria require "water, certain mineral salts, and some sort of nitrogen"? State definite reasons for each.

7. Why do we identify decay as a result of respiration?

8. Of what, if any, benefit is putrefaction to the organism which causes it?

9. What is the difference between a saprophyte and a parasite? How do both differ from green plants?

10. What is a disease? Can you name some disease not caused by bacteria?

11. How is it possible that the bacteria which *cause* a disease can also be used to *prevent* it? Explain thoroughly.

12. What is a culture? Name four cultures that you have seen in the laboratory (four different kinds of plants).

13. In Pasteur's experiment with anthrax in sheep, why were only 25 sheep vaccinated and 50 inoculated with anthrax? Why were 10 animals left untreated?

14. What is a colony? Is a root a colony? Explain.

15. What is a vegetative cell? In what other connection have you already used the word vegetative?

16. How many bacteria are there in a liter of milk containing 1,000,000 per cubic centimeter? How is it possible to count the number in a cubic centimeter?

17. What is the "mother" of vinegar?

18. What do we mean when we say we "preserve" some fruit?

19. Why does moist grain "heat" in the bins?

20. What is the difference between complete and incomplete respiration?

21. Mention as many as you can of the products of bacterial life, including some that are agreeable or useful to man, and some that are unpleasant or harmful.

22. In what parts of the earth are bacteria abundant? In what parts are they scarce? What factors are connected with their distribution?

23. How many bacteria .0015 mm. long would be required, placed end to end, to reach across your thumb-nail?

24. Is bacteriophage alive or not? What test do we apply to things to determine whether or not they are alive?

25. If a cubic centimeter of a liquid contains 500,000 bacteria, and this cubic centimeter is diluted with 9 cubic centimeters of sterile water, how many bacteria are there per cubic centimeter of the mixture? Repeat the process four times, each time diluting one cubic centimeter of the liquid obtained in the last step with 9 cubic centimeters of sterile water; how many bacteria are there per cubic centimeter of the final mixture?

Yeasts

1. Why are not yeasts classed with bacteria?

2. Is yeast the only sort of plant which can respire anaërobically?

3. Of what use is alcoholic fermentation to mankind? Of what use is it to the living yeast plant?

4. To what process of green plants does fermentation of yeast correspond? To what processes of bacteria does it correspond?

5. How does cell division differ in yeast and bacteria?

6. What is germination? Can you name any bodies other than spores which may germinate?

7. What is an endospore?

8. Explain the use of yeast in bread-making. How is it that mankind was able to use yeast in this way thousands of years before any man had ever seen a yeast cell or knew that it was a living plant?

9. List the parts of a living yeast cell, and contrast them with those of a living cell of a leaf of *Elodea*. What is the chief morphological difference? What is the chief physiological difference?

10. Comment on the following quotation:

"Why does the juice of the grape not ferment in the fruit itself?

We know that ripe grapes, even when cut from the vine, exhibit no such tendency; they dry up, and shrivel, becoming raisins, but never fermenting, so long as the skin is entire. It was once supposed that this arose from the gluten, or ferment, being in distinct vesicles, or cells, from those containing the saccharine juices, and consequently fermentation could not ensue, till the fruit was mashed or broken, so as to mix these ingredients. But Gay Lussac found that when grapes were bruised and carefully excluded from the air no change ensued; but that even a momentary exposure of the pulp to the air, or oxygen gas, was enough to communicate to it the power of fermentation. This seems to arise from some recondite action of oxygen on the glutinous principle of the grape. It is curious how perfectly the exclusion of air is provided for by the natural texture of the grape skin, which does not allow its ingress in the smallest degree, though it admits of transpiration of the aqueous vapor, as is shown by the desiccation of the fruit." (From Comstock's Chemistry, 1856.)

Bread Mold

1. Does damp air cause bread to mold?

2. How do we know that bread mold is a living plant?

3. What is the difference between a bacterial spore and a mold spore?

4. Why do we use the dead language, Latin, by which to designate the species of plants? Why does every plant have two names? If only one of these names is used, is it the genus-name or the species-name? Why?

5. Explain the difference between a genus and a species; between a species and a variety.

6. Is *Rhizopus* a one-celled or a many-celled plant? Explain.

7. Is *Rhizopus* a colony? Explain.

8. What must happen to the food in bread before it is of use to a mold? What agent could cause this change?

9. Why cannot jams and jellies, which contain very large quantities of dissolved sugar, acids, and other substances, be preserved from molds so easily as from bacteria?

10. What is the advantage to the mold of the possession of spores?

11. A piece of moist bread is placed in a box. Two weeks

later *Rhizopus* zygotes are found upon it. Outline all the events which led to the presence of these bodies.

12. In what sense is a zygote a spore? How does it differ from other spores?

13. Is a life-cycle (or life-history) the history of one individual or of several? When we say that a life-cycle deals with the reproduction of a plant, do we mean one individual plant or a species of plants?

14. Why does a jar of jelly mold if left open in an ordinary temperature? Why does it not mold until the air-tight covering is removed?

15. Why can foods be preserved against mold and other saprophytes by keeping them in an ice-box?

16. What is the fundamental physiological difference between *Rhizopus* and a geranium?

17. *Rhizopus* can be grown in a nutrient solution containing, dissolved in water, sugar, and inorganic substances which incorporate all the various elements used by living matter. If the sugar is omitted, the mold does not grow. Why? If the substance containing nitrogen is omitted, the mold does not grow. Why?

Reproduction

1. What is common to all methods of reproduction?

2. Name the kinds of reproduction exhibited by *Rhizopus*.

3. Distinguish between a one-celled organism, a colony, and a many-celled organism.

4. What is a spore? Are all spores alike?

5. What is a gamete? Are all gametes alike?

6. If *vegetative* means *not concerned with reproduction*, what can be the meaning of *vegetative reproduction?*

7. What is the distinction between reproduction and growth? Which name should we apply to the formation of a colony by a bacterium?

8. Give a definite example of a plant of which the immediate offspring does not resemble it.

9. If the offspring does not resemble the parent, how do we know that they belong to the same species?

10. What is the connection between cell division and reproduction?

11. What parts of a cell do you think most important in maintaining the constancy of a species? State your reasons.

12. In what sense is protoplasm immortal?

13. What is the advantage to a species of reproduction?

The Fungi

1. Why do we classify plants?

2. What similarities do we use in grouping plants, and why?

3. Show what would be the disadvantage of classifying trees according to the sizes and shapes of their leaves.

4. What is the difference between a natural and an artificial system of classification?

5. Plants have been grouped in many different ways during the growth of biology. Do you think our present grouping will remain unaltered? Discuss thoroughly.

6. What is the chief morphological difference between the fungi and the algae? What is the chief physiological difference? To what great group of plants do they both belong?

7. What is a thallus? What plants that you have already studied consist of thalli?

8. Name four groups of fungi, and give definite examples (with genus-names when possible) of each group.

9. Do all fungi cause diseases? Are all diseases caused by fungi?

10. Name five saprophytes and five parasites.

11. Explain the practical importance to the human race of a knowledge of the life cycles of fungi. Give definite examples.

12. What is meant by the "control" of a disease? State three methods of control of diseases of plants.

13. What is a coenocytic plant?

14. Does wet weather cause potato blight or mildew? Explain.

15. What is a spore? Distinguish between endospores, zoöspores, ascospores, basidiospores, conidia.

16. How may spores be formed? Distinguish between sporangia, basidia, asci, conidiophores.

17. Why is yeast classed as an Ascomycete?

18. What is an haustorium? What is the difference between an inter-cellular and an intra-cellular parasite?

19. What is the effect of the presence of *Phytophthora* on the cells of a potato leaf? What is the effect of the presence of *Puccinia* on the cells of a barberry leaf?

20. Why are morels found usually near trees, among the fallen leaves?

21. Explain how the United States Department of Agriculture hopes to control wheat rust by eliminating the barberry. Will this method entirely eliminate the disease? State your reasons.

22. Shelf fungi are able to push their delicate hyphae into hard wood, causing decay. How are they able to do this? Why is a tree so infected more liable to be blown down than a healthy tree?

23. How many spores are formed by a puffball? Do they all germinate?

24. Comment on the following statement: Plants are distinguished from animals by their green color.

25. In what form does mildew live through the winter?

26. In what form does mildew spread from host to host?

27. In what form does a mushroom exist as a single cell?

28. Explain the terms mycelium, hypha, rhizoid, sporangiophore.

29. What is the structural difference between the stipe of a mushroom and the stem of a sunflower?

The Algae

1. What is plankton?

2. It is said that fish are more abundant near the surface in the North Sea after a period of sunny weather. Can you explain this?

3. The text states that direct sunlight is injurious to living protoplasm. How then do you account for the fact that many plants do live in direct sunlight? How do their cells differ from a cell of *Protococcus?*

4. Is *Spirogyra* a colony or a many-celled plant? What difference does it make in our discussion?

5. Would you name the following events growth or reproduction:
   (*a*) The division of a bacterial cell;
   (*b*) the division of a *Protococcus* cell;
   (*c*) the division of a *Spirogyra* cell;
   (*d*) the division of a zygote of *Fucus?*

6. What process determines the shape of a colony?

7. What agency might bring about the dissolving of the cell walls of the buds which form the conjugation tube of *Spirogyra?* Of what are the cell walls of *Spirogyra* composed? Is this substance soluble in water?

8. What gases enter and leave a cell of *Spirogyra* in the sunlight? In darkness?

9. Why does a zygote of *Spirogyra* remain alive under conditions (such as the lack of water and low temperature) which cause the death of vegetative cells? Name bodies possessed by the fungi which are of similar usefulness.

10. What is a gamete? How do the gametes of *Rhizopus* differ from those of *Spirogyra*, *Fucus?*

11. Describe the differences between the two gametes which unite to form a zygote of *Fucus*. What are oögonia and antheridia?

12. Microgametes are produced in vast excess over the megagametes. Is this of any advantage to the species?

13. What is the outstanding physiological difference between a zoöspore of *Ulothrix* and a microgamete of *Fucus?*

14. How many kinds of individual plants can you recognize in the life cycle of *Fucus?*

15. Name five genera in the Chlorophyceae, five in the Phaeophyceae, five in the Rhodophyceae.

16. What are Diatoms? Of what economic importance are they, and why? What is our source of supply?

17. What is the chief importance of the algae to man?

18. What would result if no differentiation occurred during the growth of a *Fucus* zygote? Can you name an alga in which this does happen?

19. Would you expect to find a fungus growing on a moist rock? Would you expect to find an alga growing on a moist rock? Explain.

20. In inland lakes which contain large quantities of suspended matter, algae and other green plants are found only in relatively shallow waters (to about thirty feet), while in some of the oceans they are found at depths of several hundreds of feet. How do you account for this?

21. What are lichens? How do they reproduce?

22. What enables lichens to grow on dry rock surfaces, where algae could not get enough water and fungi could not get organic material?

23. With what other kinds of plants besides algae are fungi associated to the advantage of both?

24. What is the difference between parasites and epiphytes?

25. What does the word Phycomycete mean? Can you name a genus of algae which closely resembles a genus of fungi? In what respect do they most resemble each other?

26. Do you think any of the fungi might be related by descent to any of the algae? State your reasons.

The Ferns

1. State two reasons why ferns are not classed with Thallophytes.
2. What is a rhizome? Can you think of any other plants besides ferns that possess rhizomes?
3. State all the differences you know between the stem of a fern and that of a sunflower (manner of growth, external appearance, internal structure).
4. State all the differences you know between the vascular bundle of a fern stem and the vascular bundle of a sunflower stem.
5. Why is a fern stem of approximately the same diameter throughout its length?
6. Why do the trunks of tree ferns not make good lumber? Do you think they could be used as posts in building?
7. Why do tree ferns not grow in temperate climates?
8. Which of the following processes occur in ferns: photosynthesis, respiration, translocation, digestion, transpiration, fermentation, reproduction? State the advantages or disadvantages of each to the plant.
9. Why is a bulbil not called a spore? What is vegetative reproduction?
10. Distinguish between sporophyte, sporophyll, sporangium, spore mother cell, spore. What is a sorus?
11. Explain the terms haploid and diploid.
12. Explain the essential differences in mechanism between reductional and equational mitosis.
13. Why are fern spores found in groups of four?
14. If a fern zygote contains 120 chromosomes, how many will be present in each cell of the mature plant into which it grows? Why? How many will be present in each spore mother cell? Why? How many will be present in each spore? Why? How many will be present in each cell of the mature gametophyte? Why?
15. What are the meanings of the words sporophyte and gametophyte? From what reproductive cell does each develop?
16. Does differentiation occur during the growth of a fern spore? Explain. What sort of plant might result if no differentiation occurred?

17. How many distinct kinds of individuals can you recognize in the life cycle of a fern? Which one has the best title to the name fern? Why?

18. What light does the fern throw on the common definition of inheritance, namely that inheritance is what makes the offspring resemble its parent?

19. Compare the antheridium of a fern with that of *Fucus*. Compare the archegonium of a fern with that of *Fucus*.

20. Enumerate all the differences between microgametes and megagametes of a fern.

21. What is the advantage, if any, of the possession of large numbers of microgametes?

22. Is a megagamete of a fern fertilized by the microgametes from the same prothallus? Explain.

23. What causes the microgamete to move? What enables it to reach the megagamete?

24. Why do fern prothalli not reproduce in dry places?

25. What is an embryo? Of what parts does a fern embryo consist? Do all these parts develop into permanent parts of the mature plant? Explain.

26. Can you now explain the significance of the peculiar nuclear divisions which occur during the germination of the zygote of *Spirogyra?*

27. In what ways are fossils formed? How do they tell us anything of life on the earth thousands of years before the advent of man?

28. Name five genera of ferns.

29. At what point or points in its life cycle does a fern exist as a single cell?

Bryophytes

1. A liverwort has no roots, stems, or leaves; why is it not classed with Thallophytes?

2. A moss has stem and leaves. How is it possible to place it in the same group as liverworts?

3. What is the advantage to a moss of its erect manner of growth?

4. What is the difference between a root and a rhizoid? Between a rhizoid and a rhizome?

5. Name two genera of mosses, two of liverworts.

6. In what ways is it true that the reproduction of a moss resembles very closely that of a fern?

7. Does the antheridium of a Bryophyte most resemble that of a fern or that of *Fucus?*

8. What is the source of food for a moss gametophyte? For a moss sporophyte? For a fern gametophyte? For a fern sporophyte?

9. Explain the presence of the calyptra on a moss capsule. To which generation does each of these structures belong?

10. What other kind of plant resembles the protonema of a moss? How might you be able to distinguish the two?

11. Mention all the means of vegetative reproduction found in mosses.

12. What other plant part has an internal arrangement of cells and air spaces like those of *Marchantia?* Of what advantage is this sort of structure?

13. What are gemmae? How do they differ from spores?

14. Into what sort of a plant does the spore of a moss develop? The spore of a fern? The zygote of a moss? The zygote of a fern?

15. What sorts of situations are inhabited by mosses?

16. What sorts of situations are inhabited by liverworts?

17. It is commonly said that moss grows more abundantly on the north side of a tree, and that this fact can be used as an indication of directions in a forest. If this is true, can you explain it?

Club Mosses

1. Which of the following are true mosses: *Mnium*, *Selaginella*, reindeer moss? Explain the basis for your classification of these plants.

2. If you found an unknown leafy plant, bearing no fruits or seeds, how would you determine whether to class it with Bryophytes or with Pteridophytes?

3. What is a strobilus? Can you name any other plants besides club mosses which have strobili?

4. Do megaspores and microspores unite to form a new individual? Do megagametophytes and microgametophytes unite?

5. If a microspore means a small spore, does a microsporophyll mean a small sporophyll? Explain.

6. What results from the germination of a moss spore; of a fern spore; of a *Selaginella* spore?

7. Where does reductional division occur in *Selaginella?*

8. Compare the gametophyte of *Selaginella* with that of a moss and with that of a fern, as to (*a*) structure; (*b*) nutrition; (*c*) means of reproduction.

9. What evidence have we for saying that the spores of certain liverworts are not all alike, although they look alike? Are such plants heterosporous?

10. What are the Fern Allies? Name and describe some of them. Why are they classed with the Pteridophytes?

11. Why is *Equisetum* sometimes used for scouring? Do you know of any other plants having a similar property?

12. Review the definitions of spore, sporangium, sporophyll, sporophyte; and the alternation of generations.

13. To a young leafy plant of *Selaginella* is attached a small round knob-like structure just where root meets stem. What is this structure, and how does it come to be attached to the young plant?

The Pine

1. How does a seed differ from a spore or a zygote?

2. Do any of the Gymnosperms resemble ferns? Is their method of reproduction at all similar? Do you think they might be related by descent to ferns?

3. Which transpires water most rapidly, a pine leaf or a sunflower leaf? Why?

4. How long does a pine leaf remain on the tree? How long does an oak leaf remain on the tree? Can you explain how the former kind of leaf is fitted to stay on as long as it does?

5. How do we know that a pine tree is a sporophyte?

6. What justification have we for regarding the pollen grain and the megagametophyte in the ovule as individual pine plants rather than as parts of the tree?

7. Compare the gametophytes of a pine with those of club mosses, ferns, and mosses.

8. Criticize and explain the following statement: the microgamete of a fern moves to the megagamete through water; that of a pine through the air.

9. What part does the pollen tube play in fertilization? Is any such structure found in ferns?

10. What is a stamen? A carpel? An ovule? A pollen grain?

The nucellus? Can you explain the fact that these parts of seed plants should have each two names, quite different in derivation?

11. Why do we state that the pollen grain is not a gamete? How could one determine whether or not a body was a gamete?

12. Can you account for the clouds of "sulphur" which fly out from some pine trees in the spring when they are shaken?

13. Is it of any advantage for a pine to produce many more microspores than megaspores? Explain.

14. What is growth? Does it always and in all plants involve the same processes? Give examples.

15. What is the source of food for a pine megagametophyte; for a young pine microgametophyte; for a mature pine microgametophyte; for a pine sporophyte? If any of these are parasitic, specify the exact tissue from which they obtain food.

16. Describe a pine microspore, a pollen grain, and a mature microgametophyte.

17. How do pine microgametes differ from fern microgametes?

18. Explain the statement that the spores of a pine are both morphologically and physiologically different. What other situations are possible?

19. What agency carries the microgametophyte to a point near the megagametophyte? What agency carries the microgamete to the megagamete?

20. Distinguish between pollination and fertilization.

21. What is an embryo? Name the parts of a pine embryo, and compare with those of a fern embryo.

22. No matter which side up a pine seed falls, one tip of the hypocotyl, when it grows, penetrates the soil; while the other end finally extends up into the air. Explain how this is possible.

23. What sort of division (equational or reductional) occurs in the growth of a pine microspore? In the growth of a pine megaspore? In the growth of a pine zygote? In the reproduction of a pine spore mother cell?

24. Are the following structures haploid or diploid: pollen grain, microspore, megagametophyte, spore mother cell, ovule, carpel, root, pollen tube, megagamete, zygote, embryo?

25. What is the chief economic importance of the Gymnosperms?

26. Outline the various steps necessary to the formation of a pine seed. Show how this involves several individuals and several separate acts of reproduction. How long does it take?

27. Of what sorts of tissue is pine wood composed? Of what is the bark composed? How does the wood increase in diameter every year? How does the bark form its very rough, hard, outer surface?

ANGIOSPERMS—SEEDS, SEEDLINGS, AND MATURE PLANTS

1. Mention as many as you can of the ways in which Angiosperms are used by man. Name specific examples of plants used in the various ways you mention.

2. Name two seeds having all four possible parts of a seed, two lacking perisperm only, and two lacking both perisperm and endosperm.

3. Compare an Angiosperm seed with a Gymnosperm seed.

4. What advantages does a seed have over a spore or a zygote?

5. Of what use to the plant is the food stored within the endosperm of a persimmon seed?

6. How must the food in the endosperm be changed before it is of use in germination? Why? What agent effects this change?

7. To what do the terms monocotyledonous and dicotyledonous refer? Name all the differences you can between these two kinds of Angiosperms, and give examples of each.

8. What are the first requirements of a seed for germination? What process and what substance is most concerned in the enlargement of plant cells? At what times of year do seeds usually germinate, and why?

9. What is the commercial source of diastase?

10. What is the *reason* diastase is present in a germinating seed in large quantities? What is the *advantage* of such an arrangement?

11. What is a bud? Name all the kinds of buds you know. What effect do the kind and arrangement of buds have upon the form of the mature plant?

12. How does the bean embryo differ from that of the persimmon?

13. How do the cotyledons differ in structure and in function in the following embryos: buckwheat, pea, bean, corn? Compare with the cotyledons of pine and of fern.

14. What peculiarity of the epicotyl is often associated with enlarged fleshy cotyledons? Explain the advantage of this to the plant.

15. From what part or parts of the embryo does a mature

fern plant develop? A mature corn plant? Describe the growth of both.

16. Name some of the chief environmental factors which contribute to the form of a mature plant as it develops from an embryo. What else besides the environment helps to determine the appearance of the plant?

17. What is an adventitious root? In what other connection have you already used the word adventitious?

18. Name the principal functions of the following: xylem vessel, sieve-tube, root epidermis, stem epidermis, palisade tissue, spongy tissue, vein, cambium. Review the structure of each.

19. Indian pipe is an almost colorless saprophyte. Why is it not classed with the fungi?

20. Name as many epiphytes, saprophytes, parasites, as you can. In what groups of plants besides Angiosperms do they occur?

21. How could you determine whether a plant has many small simple leaves arranged along branches, or large compound leaves having small leaflets arranged along the midribs?

22. What are tendrils? How could you determine whether a tendril was a modified leaf, leaflet, or branch?

23. How could you determine whether the thorns on a rose or a locust were leaves, stipules, hairs, or branches?

24. What is the difference between a corm, a bulb, and a tuber? What are the "bulbs" of a dahlia? Of a crocus? Of a tulip?

25. What is the advantage to the plant of enlarged subterranean storage organs? What is their advantage to man?

26. Why does the absence of leaves (or their reduction to small spines) better fit a cactus to live in a desert?

27. Describe the peculiarities of a pond lily that enable it to live in water.

28. Are the insect-catching mechanisms of certain plants of any benefit to them?

29. What is a stimulus? A response? Do any plants other than the insect-catching plants exhibit responses to stimuli?

30. Are all plants adapted to the same environment? Can plants "adapt themselves" to new environments?

31. Are all the plants in one place adapted to the same general environment? Are they all adapted in the same way?

32. What is the reason that a pond contains only plants adapted to life in water, a desert only plants adapted to very arid conditions? Is this what caused the various adaptations to develop? Explain.

Angiosperms—Reproduction

1. Why is quack grass hard to eradicate from a garden?

2. When a plant reproduces by vegetative means, does its offspring resemble it or not? If the parent is diploid, is the offspring diploid or haploid?

3. What is a flower? State the differences between flowers and cones.

4. To what generation does a flower belong, sporophyte or gametophyte? How do we know?

5. Why are the stamens and carpels alone considered the "essential organs" of the flower? Of what advantage, if any, is the possession of the perianth?

6. What right have we to consider the carpels and stamens of a flower to be leaves, seeing that they have little resemblance to leaves? State two reasons.

7. In a "double" peony, rose, or geranium, what is the origin of the extra rows of petals? How does such a plant reproduce?

8. What is the outstanding peculiarity of an Angiosperm megasporophyll?

9. What is a pistil? In what way does it differ in different sorts of Angiosperms?

10. "Angiosperm" means "enclosed seed." What structure encloses the seed? To what does this correspond in the pine? In the fern?

11. What is an ovule? Compare the ovule of a buttercup with that of a pine. Is there anything in a fern corresponding to an ovule?

12. Why do we use flowers rather than leaves, stems, or roots by which to classify Angiosperms? A grape is not considered related to a morning-glory, though both have twining stems, nor to a cucumber, though both have tendrils; a tomato plant is related to the Jimson weed and to the tobacco plant, much as they differ in appearance.

13. Explain why we can speak of the edible part of an apple as a stem, and of that of the cherry as a leaf.

14. From what body does a seed develop? From what does a fruit develop?

15. Compare single flowers of the following: a cat-tail, a willow, a buttercup, a pea, an apple, a lily, a peony, as to (*a*) kinds of organs present; (*b*) numbers of parts; (*c*) union of parts; (*d*)

regularity; (*e*) shape of receptacle; (*f*) origin of fruit; (*g*) type of fruit.

16. Why do we consider a grain of corn a fruit rather than a seed?

17. The gametes are formed within the parts of a flower. Why is a flower, then, not a gametophytic structure? Explain fully.

18. Compare the mature gametophytes of the following plants: lily, pine, fern, moss.

19. In what ways does a mature microgametophyte of an Angiosperm resemble a parasitic fungus?

20. How does pollination in a pine differ from that in an Angiosperm? Why does the pollen tube have a greater distance to grow in the latter?

21. What is the origin of the endosperm of a seed? Why is it triploid? Compare with the origin of the similar-appearing food storage tissue of a pine seed. To what generation does the latter belong, and why?

22. Why are several varieties of pears commonly planted together in one orchard?

23. Comment on the statements: "Most flowers are constructed as they are in order that they may ensure cross-pollination." "Flowers have acquired petals because of their need to attract insects."

24. Why do insects visit flowers? Why are flowers constructed so that they are of use to insects?

25. What is a fruit? To what in a pine does it correspond?

26. Why do we say that the "seed" (stone) of a cherry is not really the seed?

27. Why is a strawberry not considered (botanically) a berry, while a banana is? What would be the difficulty in defining the word berry so as to include strawberries?

28. What type of fruit does the pistil of a strawberry flower develop into? What forms the edible portion? Compare with the apple flower and fruit.

29. Define the following types of fruit: follicle, legume, capsule, achene, nut, samara, caryopsis, berry, pome, drupe. Give an example of each.

30. What is an aggregate fruit? What is a multiple fruit? Give examples.

31. Draw a diagram of a typical complete Angiosperm flower

as seen when cut longitudinally through the receptacle. Label all parts and show by labels where the gametophytes are located.

32. Of what advantage to the plant is the juicy flesh of a drupe or berry? State two reasons.

33. Fruits whose outer parts are soft and edible have seeds protected by stony layers or seed coats. What would happen to them if this were not so?

34. If a native forest is cut down, the ground is often afterwards covered with kinds of plants which were not previously known to grow within hundreds of miles of that place. Explain.

35. Are fragrant odors and bright colors of any advantage to flowers?

36. Flowers that open at night are frequently large and light-colored. What might be the result if they were otherwise?

37. What is the advantage to the plant of the sharp hooked spines on a cocklebur?

38. What part of the plant gives rise to the tuft of hairs on a dandelion fruit and to the hairs on a milkweed or cotton seed? What is the use to the plant of these hairs?

Inheritance

1. When we say the offspring of an apple tree is another apple tree, to what generations are we referring? What is omitted, and why?

2. What is biological inheritance? What other kinds of inheritance are there?

3. Is its inheritance the only factor which gives an individual its particular appearance and characteristics?

4. What is Genetics?

5. Outline the various steps in reproduction by seeds, showing when segregation takes place, and when gametes unite.

6. Why is an apple tree propagated by grafting rather than by its seeds? Explain thoroughly.

7. What is a "bud sport"?

8. If a Jonathan apple scion is grafted on a Ben Davis stock, what will be the character of the apples produced on the scion? Explain.

9. In what part of the cell are genes thought to be located? Give as many reasons as you can for your answer.

10. Under what conditions does a plant containing genes for

the development of chlorophyll not become green? What else must be present in a cell, besides the genes, for the development of chlorophyll? Do you think this is true also of other characters?

11. If the genes were in the cytoplasm, what would happen to them during reproduction by seeds? What sort of offspring might one expect?

12. If the genes were not arranged in rows along the chromosomes, what would be their distribution to the daughter cells?

13. What are fortuitous variations?

14. What conclusion can you draw from Johannsen's results? Does this have any practical importance? Explain.

15. What is a pure line?

16. Explain the terms heterozygous and homozygous.

17. What is a mutation?

18. Summarize all the assumptions made in explaining the mechanism responsible for the three to one ratio. What justification have we for believing these assumptions to be true?

19. Why is the three to one ratio of the F_2 generation not exactly three to one, but only approximately so?

20. Explain how it is possible to obtain by breeding offspring different from either parent, even without the occurrence of mutations and in the same environment as that in which the parents developed.

21. How did Burbank, the "plant wizard," "create" new kinds of plants?

22. List all the factors you can think of that make a corn embryo grow into a corn plant rather than into a horse or some other kind of organism.

23. When a breeder wishes to obtain new combinations of characters, which method of reproduction (by seeds, or by vegetative means) does he use in propagating the plants in which he is interested? Why?

24. A red sweet pea is crossed with a white sweet pea. Red is dominant over white. What sort of offspring is obtained? If the offspring is self-pollinated, what will be the character of the next generation?

25. A plant containing the two pairs of genes *AA* and *BB* is crossed with a plant containing *aa* and *bb* instead. Show by diagrams how the members of each pair segregate in reproduction, what possible kinds of gametes result, and what new combination of genes is found in the next generation.

26. Repeat question 25, starting with the offspring there obtained as a parent and self-pollinating it.

27. In a cross of tall by dwarf pea plants, the second generation is composed of three quarters tall plants, one quarter dwarf. How could you demonstrate that there are really two genotypes among the tall plants, in the ratio of one to two, although they all look alike?

28. Assuming that the Delicious apple has 14 heterozygous pairs of genes on 14 pairs of chromosomes, how many phenotypes are theoretically obtainable by self-pollination?

Review the questions on the Formation of New Cells.

Biologic Evolution

1. What facts does evolution explain?

2. Are there other possible explanations for these facts? Why is evolution the preferred one?

3. In what sense is our classing of plants into families, genera, and species artificial?

4. Is it probable that if we had existed in the carboniferous age our classification of plants would not have given us the same groups as those we have now? Why?

5. Why does the evidence of fossils make the theory of Special Creation hard to believe?

6. Does the fossil evidence prove the truth of evolution?

7. One criticism of evolution as demonstrated by the origin of domestic plants is that new species are not formed, only new varieties. Can you discern any weakness in this argument?

8. Which of the following statements, if any, expresses best the scientific facts?

(*a*) Evolution is the development of simple forms into more complex forms.

(*b*) Evolution is the theory that man descended from monkeys.

(*c*) Evolution is the origin of all forms of life from one original form.

(*d*) Evolution is the production of new forms from old forms.

9. Can you explain why there should be large gaps in the evolutionary sequence, if we assume the truth of evolution?

10. The statement is sometimes made that since scientists have

been unable to agree on the causes of evolution, therefore they have no proof of the existence of such a process. Criticize and explain.

11. What is the present status of Lamarck's theory?

12. What is the present status of Darwin's theory?

13. What do the above theories seek to show?

14. The leaf of a water lily, in having its stomata on the upper side instead of the lower, and by reason of its shape, is admirably fitted to live floating on a pond. How would Lamarck explain these facts? How would Darwin explain them? How would DeVries explain them?

15. What is a natural law? Who enforces it? If you found a plant or a stone or a river disobeying a natural law, what would you do about it?

Distribution of Plants on the Earth

1. Name a species more or less restricted to each of the following environments: high mountains, peat bogs, freshwater pond, salt water, dry cliffs, swamps, desert. Name two species more or less widely distributed in many environments.

2. Enumerate the ways in which water affects the life of a plant.

3. Describe the chief adaptations to its environment of a cactus; of a pondweed; of a water-lily; of a bulrush; of sage-brush; of a pine; of a sunflower. Which of these are hydrophytes? Which are mesophytes? Which are xerophytes?

4. Explain why plants with large transpiring surfaces could not endure a northern winter (without shedding their leaves). What is the peculiarity of leaves which remain on the plant during the winter, and of what advantage is such a peculiarity?

5. What is "physiological dryness"?

6. Is an epiphyte usually a hydrophyte or a mesophyte? Explain. Name all the epiphytes you know.

7. How does the removal of a forest change the conditions under which the young plants there are growing? Are the same kinds of plants adapted to the new conditions as to the old? Are the plants able to "adapt themselves" to the new condition? Give evidence for what you say.

8. What is a plant association? A plant succession?

9. Explain how a xerophytic fern and a semi-aquatic liverwort may both be found in the same association.

10. What sorts of plants would you expect to find establishing themselves on a moist rock; on a dry rock; in a pool; on a vacant lot? Give specific reasons.

11. What types of plant associations do you know near your home? Is any factor changing their nature? Are they climax associations?

12. What is peat? What is the origin of the energy which is liberated as heat when peat is burned?

13. Why are high and persistent winds injurious to plant life? What kinds of plants can most successfully withstand such winds?

14. Do perennial plants shed their leaves at the same time of year in Panama as they do in Missouri? Discuss the advantages of leaf-shedding.

15. What is the connection between the study of heredity and the study of plant distribution?

16. What is the connection between the study of evolution and the study of plant distribution?

17. What is the connection between plant physiology and the study of plant distribution?

Review the last eight questions on Chapter XXIII, and Questions 32, 34, 37, 38 on Chapter XXIV.

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